CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)

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Project Title: European Pear Growth and Cropping: Optimizing Fertilizer Practices Based on Seasonal Demand and Supply with Emphasis on Nitrogen Management

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Statement of Objectives

Best Management Practices (BMP) for European pear in California were re-evaluated, using UC recommendations as a starting reference. Recommendations currently are 2 lb actual N per ton of crop per acre per year (#N_{act}/t/A/yr). Tissue N critical value is 2.2%, adequate N range is 2.3-2.6%, using non-bearing spur leaves for analyses in mid-summer. The 2007 recommendation established BMP based on two physiological premises for N management: (1) efficiency of N use in cropping -- a 30 ton/A orchard should receive 60 #N_{act}/A/yr; (2) vegetative vigor control– no N should be applied if average shoot growth exceeds 12 inches.

Diagnostic methods for nutrient sampling re-examined in this study; considerations:

Period of greatest nutrient demand: Extension shoots grow rapidly until they set terminal buds June-July. Fruit development (rapid cell multiplication followed by cell expansion) extends from fruit set until fruit are harvested; fruit size can be maximized, in part, by multiple harvests, removing the largest fruit initially and encouraging further sizing for the remaining fruit. Floral initiation for the next year's crop occurs concurrently with the last stages of fruit development for the current crop, early July to early August (later for later-maturing districts).

Timing of analyses: Analyses conducted only shortly before harvest do not allow adjustment for current season yields and quality, although they do aid in fertilizer scheduling for postharvest applications, important for return bloom nutrition and adjustment for heavy crop drain of nutrients. Spring analyses made before fertilizer applications typically begin can be used to make in-season adjustments for the current anticipated crop load, as well as to judge whether or not to forgo or reduce early nutrient applications to reduce vigor (where possible). Spring-applied nutrients support vegetative and reproductive growth in-season and floral initiation for the next year's crop. Postharvest leaf analyses indicate the differential between nutrient levels prior to and after harvesting due to crop drain and also indicate timing of nutrient remobilization for storage purposes. If nutrient levels are deficient postharvest, it is important to be able to bring nutrient levels up to adequacy for the return bloom, and to apply those nutrients when they can be effectively taken up and stored.

Tissues used for nutrient analyses: Current California recommendations are to sample mid-summer non-bearing spur leaves, which mature soon after bloom and leaf-out. These leaves are ~3 months old at sampling and are not part of an actively growing 'unit', as are leaves on extension shoots or leaves on bearing spurs. It is possible that leaves collected from vegetative extension shoots, as is common outside of California, or from fruit-bearing spurs, where demand is likely to be highest, may prove to be a better indicator of nutrient status for cropping. Fruit quality is dependent on N, Ca, K, Mg and P (and their 'balance'); optima should reflect current strategy of maximum yield and 'target fruit'. High nitrogen is considered detrimental to fruit quality, as a balance among nitrogen, calcium and potassium, particularly. Not all nutrient status in leaves is indicative of nutrient status of fruits (e.g. Ca).

Current California pear growers' practices: Grower practices vary widely on both sides of the recommendations and grower choices for fertilizer management are also based on a much wider set of parameters than recommended BMP alone. Vegetative vigor management according to the recommendations is difficult if not impossible in the Sacramento Delta District, where typical annual shoot growth can be more than 3 ft per year. If a high percentage of growers make choices that deviate significantly from the recommended BMP and many find tissue nutrient analysis a minor concern (as observed among growers of the range of tree crops in California; Weinbaum et al., 1992), perhaps it is time to clarify why this is so and consider bringing recommended BMP more in line with what the growers perceive as appropriate for their crop.

This study addressed CDFA/FREP goals of research-based development of cost-effective fertilization practices to improve N fertilizer use efficiency and minimize environment impacts in European pear production. Similar benefits can result from adjustment of other macronutrient fertilization practices for fruit quality and yield. The FREP program goals aligned with this project include 1) nutrient uptake by tree crops, including determination of tissue nutrient thresholds, 2) guidelines for orchard fertilization patterns, including foliar nutrient management and effective fertilizer timing, and 3) dissemination of the information developed to the growers and PCA's who make management decisions.

Project Objectives:

1. Determine the relationship between seasonal tissue N partitioning and concentration and tree productivity and growth (i.e. reassess the currently-accepted leaf N critical values, timing of sampling and tissues tested). **Orchards Elliot I and McCormack**

   Note: sampling of some tissues (e.g. non-bearing spur leaves on some dates) had to be eliminated from originally planned protocols due to unanticipated multiple price increases at the diagnostic lab. This was unavoidable as State budget shortfalls resulted in drastic financial support to UC and many program areas lost funding. Over the three-year project period, adjustments were made as needed and without surety of future pricing stability.

2. Compare typical and reduced N to validate recommended N management and the possibility of customizing BMP based on tissue levels, fruit quality and crop load **Orchards Elliot I and McCormack**
3. Quantify effects on crop load and fruit quality due to N, K and Ca as influenced by application amount, form and timing **Orchard Elliot II**
4. Refine current management guidelines for fertilizer usage to maintain productivity and fruit quality while reducing potential of over-fertilization **Orchards Elliot I and II , McCormack**
5. Monitor growers' irrigation practices in each trial site with the goal of optimum irrigation management to reduce nitrate leaching. Cooperate with growers to follow recommended irrigation frequency as outlined by UC recommendations (Pear Production and Handling Manual, UCANR Publication 3483, Mitcham and Elkins (eds), 2007) **Orchards Elliot I and II, McCormack**

Executive Summary: Main Findings, Conclusions and BMP Recommendations for Orchard Trials

Project Objective 5: Irrigation practices and their role in nutrient management: All trial orchards utilized water budget management that considered orchard soil texture, slope, irrigation system in place, water source and quality, whether the orchard had sod or clean floor culture, and tree density (these were fixed constants), weather patterns (temperature and rainfall), tree vigor (a function of rootstock, soil type, water table/availability, and nutrition) and cropping, and fertilizer application timings and forms. Pear trees grown in California's Central

Valley require almost twice the annual water as trees in the North Coast District. Delta trees are more vigorous and are grown under higher heat conditions, thus have a higher evapotranspiration rate, resulting in daily water deficit during the majority of the growing season. There are no significant plantings of size-controlling rootstocks in California, thus vigor control via rootstock selection (in new plantings) is limited to the variability of existing California rootstocks.

Pear yields are directly related to soil moisture (Westwood et al., 1964) among other factors; buds may be 'forced' (grow and flower) prematurely by irrigation after severe water stress or defoliation and warm ambient temperatures. Water stress during floral initiation (pre- to postharvest) reduces the next year's crop. The main factors affecting tree performance as related to water supply (soil type, irrigation frequency and depth or water penetration, and external moisture stresses – wind, temperature, rainfall, etc) are site-specific and the growers in these trials have long histories of managing these orchards effectively for cost, production and sustainability. Irrigation frequency throughout the growing season was aimed at maintaining field capacity without over-watering, to maximize nutrient uptake and fruit growth without unnecessarily predisposing the trees and crop to disease/pest pressures or crop compromises. Irrigations are avoided when fire blight predictive modeling shows that humidity and temperature increase susceptibility, during the bloom period. Overwatering affects trees adversely in many ways and soil type and rootstock show variable influences.

Elliot I: Irrigation was by low-volume sprinklers. Spring fertilization of a broadcast application of $Ca(NO_3)_2$ was made once irrigation began. Postharvest broadcast application of $(NH_4)_2SO_4$ was made in some years only, in September. This site was immediately next to the Sacramento River, has a high water table and severe fire blight pressure. The grower was well-aware of BMPs for water, nutrients and disease. His was one of the lowest N use orchards in this district, thus was a prime candidate for low N management. He monitored water, soil and tissue nutrient levels annually, and obtained his irrigation water from the Sacramento River. The orchard floor was 'clean' and water and nutrient needs have taken that factor into account.

Elliot II: Both grower and manager (his family were the planters and owners of this orchard until shortly before the trial started) were very conservative in their management practices, budgeting inputs with close attention to effectiveness. Water was applied at about 0.1" per hour, annual N applications have been 'skipped' on-and-off for several years when vigor and cropping indicated lack of need and K fertilization what changed from fall broadcast to spring fertigation for ease of adjusting amount on a 'crop need' basis. The orchard floor was mown sod and managed accordingly with respect to water and nutrition.

McCormack: Irrigation was by a solid-set sprinkler system at, installed to replace flood irrigation and to reduce water loss due to the inherent N-S slope along the rows. This allowed better water infiltration and equalization of the two orchard halves, which differ dramatically in vigor. Fertigation with CAN-17 in 6-7 applications May/June-preharvest (beginning was timed to seasonal temperatures and precipitation) was applied equally to both halves of the orchard following the irrigation scheduling and the low vigor half also received a broadcast application of $Ca(NO_3)_2$. Fall application (only to the low vigor half) was broadcast MOP (0-0-62), K_2O and urea. Postharvest irrigations were at approximately 3 week intervals until seasonal rains began. The orchard floor was mown sod and managed accordingly with respect to water and nutrition.

Elliot I ('High N' vs 'Low N' = 60 or 120 #N_{act}/A/yr vs 0 N)

Seasonal tissue N partitioning and tissue levels in bearing spur, non-bearing spur and shoot leaves

- The most consistent pattern of N content differences was significantly higher N in fully-expanded shoot and bearing spur leaves in spring, prior to spring N applications (where trees had received a fall application of N), and in summer prior to harvest.
- However, even where statistically significant differences between treatments were found, the range of tissue levels was very small. Non-bearing spur leaves (currently recommended for tissue N sampling) tended not to show significant treatment differences and were within adequate to high levels, even when 0N had been applied for three years.
- No levels were inadequate in any tissues in spring or summer (preharvest) and treatment differences, when they existed, were quite small. Where treatment differences occurred within a given tissue, the 'High N' treatment consistently produced higher tissue N.

Vegetative vigor

- No difference between treatments was found in pruning weights collected February 2011.
- A weak, negative correlation was found between pruning weights collected February 2011 and April tissue N level of non-bearing spur leaves for 2010. Thus, when tissue N levels were lower, vegetative vigor was also slightly decreased; those tissue levels were not necessarily deficient, nor was vigor suppressed enough to reduce the need for pruning.
- Lack of response in vegetative growth (measured in February 2011), to differential N treatments from 2009-2010 was consistent with numerous other studies in European pear showing a general insensitivity to N level.

Reproductive vigor and yield

- Yields were not improved by increased N.
    - No statistically significant differences in yields were detected due to N treatment, although 'High N' treatment tended to result in numerically lower yields per tree and acre (in 2010 and 2012, but not in 2011). Replicate variability was high.
- 'High N' treatment tended to improve fruit size and the percentage of the crop that was #1 fruit, but this was most likely due to lower yield. Fruit size was good overall.
- 0N for three years as the 'Low N' treatment did not reduce yields or fruit quality overall, indicating that soil and tissue N levels were adequate without added N during the study period.

- The 'High N' treatment tended to result in increased fruit size while decreasing overall yields per tree and acre (the case in 2010 and 2012, but not in 2011). Cumulative tonnage per acre for 2010-2012 was 63.7 ('High N') vs 67.6 ('Low N').

- Discounting the crop loss year of 2010 (a large portion of the crop was lost to hail damage), cumulative yields per acre for 2011 + 2012 were 49.5 (High N) and 50.3 (Low N), or ~25 tons/A/year.
- **Yield efficiency (yield on a per tree basis, 320 trees/A), High N yield efficiency for 2011 was 0.09, for 2012 was 0.065 and the average for the two years combined was 0.077 at 120 #N_{act}/A/year. The yield efficiencies for the Low N (0N) treatment were: 0.084 (2011), 0.073 (2012) and 0.079 (2011 + 2012). This is the comparison that seems to make the best sense – 0N paid off for this grower these years.**

Recommendation for nitrogen application

- Under these conditions of adequacy, no benefit to added fertilizer N appears to have resulted. 0 N treatment did not reduce yields or fruit quality overall, indicating that soil and tissue N levels were adequate without added N.
- Efficiency of N use in cropping is a more powerful tool to manage N demand than either tissue analyses or vegetative growth responses. Comparing yield efficiency in the last two years of this trial when cropping was not weather-compromised showed that yield efficiency was maximized at 0N. While this may change in future and application of N will be needed, this should be managed on a 'as needed only' basis (reduction in fruit set and/or tissue inadequacy). The bearing capacity of this orchard varies from ~20-30 tons/A and variation is due more to environmental conditions (bloom weather, preharvest crop loss) and tree variability than N level. Given the range in yield and lack of increased yield with 120 #N_{act}/A/yr, 2007 BMP recommendations of 2 #Nactual/A/yr per ton/A of crop appears appropriate, at most.

McCormack orchard: Compare 'Low N' with 'High N'; compare typical and reduced N to validate recommended N management and the possibility of customizing BMP based on tissue levels, fruit quality and crop load.

The inherent tree differences in the two orchard halves due to soil texture, slope and water table that impacted N requirement were:

- 'High N, Low vigor' trees were much smaller with lower vigor, less crop, so 'loss' of N to cropping and vegetative growth may be less.
- Heavier cropping tends to dilute mineral content found in leaves; 'high vigor' trees were much more heavily cropped in this orchard.
- N applications made yearly were:

	High N, Low vigor	Low N, High vigor
2010	282 $\#N_{act}/A$	129 $\#N_{act}/A$
2011	313.5	150.5
2012	255	107.5

Seasonal tissue N partitioning and tissue levels in bearing spur, non-bearing spur and shoot leaves

- Partitioning of N into plant parts through the growing season was similar to that found at **Elliot I.**

April 2010 Baseline tissue N values

- While significant differences were found in tissue N for each leaf type between the orchard halves at the start of the trial, these were within 0.1-2%N, thus negligible. Differences between leaf types was greater than that between orchard halves.
- After differential N treatments were started, the greatest differences in tissue N throughout the trial period were due to sampling time through the growth period (spring, mid-summer, fall) and between leaf types. Slightly significant 'treatment' differences (i.e. the two orchard halves with High N, low vigor trees vs Low N, high vigor trees) were negligible in comparison. No indications of inadequacy were found. Replicate differences within each orchard half were as statistically significant as between orchard halves (treatment differences) and between leaf types. Other than the finding that no toxicity or deficiency was found for N, leaf N analysis was not particularly meaningful.

Vegetative vigor

Pruning weights collected from subsample trees were highly significant by treatment group. Not unexpectedly, the 'Low N, High vigor' trees had much higher pruning weights than did the 'High N, Low vigor' trees (63.7 vs 43.2 lb per tree, respectively; significant at 0.1%). It is probable that this difference will persist as a function of the orchard and mature trees and is not likely to change due to N treatments.

Reproductive vigor and yield; relationship between cropping and tissue N

- Yields were significantly lower for the 'High N, low vigor' treatment, in general. This was an anticipated result, due to the nature of the two halves of the orchard and was the main reason for the grower's differential N treatments.
- 2010: The percentage of the crop that were #1 fruit in the second harvest and total yield were not statistically different, although numerically, the 'Low N, high vigor' yielded a larger percentage of fruit that were #1 fruit. This finding would suggest that

the 'High N, low vigor', at the level of applied N, was probably at capacity, for this cropping year. If either half were over-cropped, fruit size would suffer; indeed, the average weights of #1 fruit and smaller fruit, by treatment, were not different. Similarly, if either half of the orchard were under-cropped, one might expect an increase in the yield of larger fruit.

- 2011: %Yield removed in the first harvest (all fruit and #1 fruit) was not different by treatment group, furthering one of the grower's goals—that an improved percentage of the crop be picked in the first harvest on the low vigor trees (i.e. maturity would be advanced).
- 2011: Tissue N for non-bearing spur leaves prior to this harvest was adequate for the 'High N, low vigor' trees (2.38% N) and slightly under the adequate range, but above critical value for the 'Low N, high vigor' trees (2.28% N). 2011 was the heaviest cropping year for this trial, so one would expect to see the results of that in tissue N responses.
- Bearing spur leaves, those that one would expect to be the strongest nutrient sources for growing fruit, showed a significant difference in tissue N in fall (2.07% N 'High N, low vigor' vs 2.13% N 'Low N, high vigor'). These two results might indicate further need for comparing both types of spur leaves before and after cropping in heavy crop years, with differential bearing habit, if possible, as in this orchard. The bearing spur leaves in the heavier cropped half of the orchard may reflect the greater demand by the crop and should be sampled.
- Comparing yields of the two halves is almost like comparing yields of two different orchards; a more meaningful measure is yield increase or decrease in response to nutrient management of each half independently, particularly as their N applications are so different.

Recommendation for nitrogen application

The grower's two primary goals in this orchard were (1) to increase the reproductive (and vegetative) vigor of the low vigor half of the orchard, by increased N application, (2) to advance maturity of the low vigor half of the orchard such that more fruit can be harvested at the 'first pick', in keeping with the ripening behavior of the high vigor half. The patterns seen in 2010 through 2012 have been generally consistent and appear to support the grower's choices. Historic yields were 20-23 ton/A/yr; a range of management strategies have increased yields to 30-32 ton/A/yr. Both halves of the orchard received a total of 152 $\#N_{act}$/A/yr until 2010; a longer record will be needed to judge the full results of this plan, however, the high percentages of #1 fruits (fairly consistent year-to-year) with good yields indicate a strong nutritional program appropriate for this situation.

Elliot II ('Budgeted' Low N and Nutrient Balance Effects on Fruit Quality and Cropping); Differential K treatment by fertigation (spring) or soil broadcast (fall)

Quantify effects on crop load and fruit quality due to nutrient tissue levels as influenced by application amount, form and timing

While nutrient tissue analyses were begun in April 2010, these should be considered 'baseline' data since the differential K program had not started. Both treatment plots had had Spring fertigation with Kmend (150 $\#N_{act}$/A/yr) in 2009. Other fertilizer applications made equally to the entire orchard: 200 lb $Ca(NO_3)_2$ was broadcast twice in spring (early May, end of June; 62 $\#N_{act}$/A/yr + 84 $\#Ca_{act}$/A/yr) and a small amount of urea was added to fireblight sprays (final $\#N_{act}$/A/yr from urea 0.7-2.76 $\#N_{act}$/A/yr) for 'fruit finish'.

April 2010 tissue nutrients

- N content was adequate after 0N in 2007-2008 and 63-65 $\#N_{act}$/A/yr in 2009.
- The greatest significant differences by 'location' (treatment plot) within a plant tissue type in this early sample were:
  - Shoot leaves – higher levels in Fertigation plot for B, Cu
  - Bearing spur leaves – higher levels in Fertigation plot for K, (K+Mg)/Ca, K/Ca and N/Ca; higher level in Soil plot for Mg
  - Non-bearing spur leaves –higher levels in Fertigation plot for Cu, Mn
- While other differences in specific nutrients and tissues were significant, none were as great statistically. In each case where a nutrient level was significantly different by 'location', the higher value was found in the 'Fertigation' plot.
- The reason for higher tissue nutrient levels in the 'Fertigation' plot trees may be that those trees were closer to the 'Scribner clay-loam' transition to 'Egbert clay'. The trial extended lengthwise away from this transition zone.
- 'Egbert clay' is described as 'Surface layer…clay about 18" thick. Below this is a buried surface layer of gray clay loam about 28" thick. The underlying material to a depth of 60" is grayish brown clay loam and sandy clay loam. In some areas the surface layer is silty clay. In other areas the dark surface layer is 14-24" thick. Permeability is slow. Available water capacity is high.'

Conclusions: 'Location' effects (probably the soil type difference with inherent permeability and uptake effects on the rootstock) were important for a particular nutrient or balance of nutrients

This trial site presented some distinct challenges due to the soil/water/rootstock interactions (the same rootstock throughout the trial for subsample trees, but varying soil nature). Since we are trying to generalize this information to suit as many combinations of rootstock and soil/water as possible, choosing a tissue that can best show nutrient changes in the tree for these factors is important to our search for the 'best' tissue to analyze for BMP. Choosing the tissue type for analyses that shows the highest number of extremes in nutrient level by 'location' could be the best single tissue to use.

Fruit had the highest number of nutrient extremes for both locations combined, and several extremes for each location. Thus, fruit nutrient levels were the most affected by the combination of rootstock x soil/water.

April 2010 nutrient correlations: Most correlations were weak, with more positive than negative. Possibly the most important correlations to pay attention to were those that involve fruit quality indicators; vigor was adequate, cropping regular and satisfactory.

Moderate correlations included:

- Negative: Mg—K/Ca in bearing and non-bearing shoot leaves (where Mg was higher in these leaves, K/Ca ratio was lower)
- Positive:
    - P-- K+Mg/Ca, K/Ca, N/Ca in shoot leaves (where P was higher in shoot leaves, these ratios of nutrients that affect fruit quality negatively when the ratio is high, were also higher)
    - P—N in fruit (where P was higher in fruit, N was lower; high N causes 'greening' in fruit and retards maturity)

Conclusions:

- Some correlations with nutrients and their interactions that may affect fruit quality, particularly postharvest, including maturation rate and ability to store and ripen without disorders, were found in early spring sampling of tissues.
- No single tissue type was clearly the best early tissue to sample for these nutrient issues. However, the greatest number of significant correlations that were moderate were found in shoot leaves; these may be the best indicators of potential fruit disorders in this case, however, further studies would provide greater confidence of this question.

July 2010 tissue analyses ('Fertigation' plot had Spring fertigation with K in 2009+2010; 'Soil' plot had Spring fertigation with K in 2009 by this harvest); both plots had been treated prior to this sampling with: ~64 #N_{act}/A + 84 #Ca_{act}/A).

Adequacy in nutrient levels:

- Shoot leaves, both treatments: K was slightly low
- Shoot leaves Fertigation treatment: Ca, Mn low
- Shoot leaves Soil treatment: N, P low
- However, no deficiency symptoms were observed, and trees had good vigor.

Differences between K treatments within leaf type:

- Shoot leaves and bearing spur leaves – higher levels in Fertigation plot for: N, P, S, Cu, and all the nutrient ratios but N/K.
- Shoot leaves and bearing spur leaves – higher levels in 'Soil' plot for: Ca, Mg, Mn, Zn.
- Bearing spur leaves also higher in 'Soil' plot for Fe.

The significance in each case was almost always the same for shoot and bearing spur leaves. These data indicate that either of these leaf types would have been equally valuable in detecting these K treatment differences, despite the fact that shoot leaves are part of a vegetative unit and bearing spur leaves are subtended by fruit. **The consistency in these results is very important as it allows greater confidence in interpretation of nutrient status.**

How do these values compare to the differences seen in the April samples?

- Shoot leaves – higher levels in Fertigation plot for Cu in both April and July
- Bearing spur leaves – higher levels in Fertigation plot for K, (K+Mg)/Ca, K/Ca and N/Ca at both timings.
- Bearing spur leaves -- higher level in Soil plot for Mg at both timings

Thus, the consistency across these tissue types in July and across sample timings for nutrients in bearing spur leaves that are important nutrient ratios in fruit quality are important findings.

Harvest and Postharvest, 2010

- There were no treatment differences in fruit quality at harvest timing.
- Yields per tree (combined 2-4 scaffold limbs) were greater in total weight harvested in the Fertigation plot, however, this could be due to differing numbers of limbs and volume of canopy represented by those limbs among the trees in each treatment. A better measure of overall yield differences by treatment is a comparison of percentage gain in yield from the same limbs over the trial period (data in discussion of 2012 harvest).
- In almost every measure of storage quality in which significant differences between K treatments were found the 2010 Spring Fertigation treatment resulted in reduced quality (firmness, all evaluation timings; %soluble solids (harvest + 3 months storage; internal browning and senescent scald). Ground color and hue angle (the first is a visual measure, the second a chromameter measure of green vs yellow color, indicating ripening) was different in some evaluation timings but results by K treatment were not consistent.
- Multivariate analysis found that postharvest firmness due to K treatments ('Fertigation' plot vs 'Soil' plot) explained treatment differences at 0.1% level with April bearing spur leaf levels of Mn and Fe (1%), (K+Mg)/Ca and K/Ca (0.1%) and Mg/Ca (5%). No other regressions explain treatment differences as well.
- The 'Fertigation' plot had higher levels for (K+Mg)/Ca, K/Ca and Fe in bearing spur leaves in April and these were among those nutrient ratios associated with firmness problems in fruit from this plot.
- Significantly higher ratios (K+Mg)/Ca, K/Ca and N/Ca in the Fertigation plot indicate that the lower Ca found in both shoot and bearing spur leaves (April sampling), although not <u>statistically</u> different by K treatment plot, were functionally different with respect to the other nutrients in balances. The significantly higher K level in bearing shoot leaves, especially, would have contributed to this imbalance.
- An important predictor of these potential fruit quality problems is the N/Ca balance in the fruit. High N/Ca status (high N/low Ca) for fruit tissue is 5.3 and low N/Ca is 4.6 (Sugar et al., 1992). The N/Ca ratio found in fruit tissues sampled in April 2010, was 12.52-13.56, indicative of exceedingly high N to low Ca balance.
- <u>Bearing spur leaf levels of these nutrients were predictive of firmness problems postharvest, as were shoot leaves and small fruit.</u>
- The July tissue analyses supported these findings. In all nutrient ratios with Ca, in both shoot and bearing spur leaves, the Fertigation plot had significantly higher ratios (i.e. lower Ca in relation to K, Mg and N) than the Soil plot.
- These results suggest that potential for storage disorders <u>was not necessarily</u> increased by the Spring 2010 Fertigation treatment (this treatment had not occurred by the April sample timing), but by the tree uptake of nutrients and their resulting balance in the tree. This was <u>likely</u> due to the proximity of these trees to the

localized soil textural differences at the transition between soil types and the water permeability of that soil.

- In this case, increasing either N or K, in response to sub-optimal levels measured in leaves in April, would exacerbate the potential for fruit disorders. Indeed, applying calcium nitrate to the soil in spring did not improve the Ca tissue levels but provided increased N, which would be contraindicated.
- Because the rootstock in the sampled trees from both plots was not different, this must be a soil/water relationship for availability and uptake of these nutrients.
- Ca uptake is passive in the water stream, moving uni-directionally (mostly) to leaves in the transpiration stream, and not laterally between leaves or from leaves to other tissues. Thus, Ca sprays must contact all surfaces of the fruit to be effective.
- Leaves from Bartlett on *P. calleryana* rootstock have had higher levels of K, Mg and B than Bartlett on some other rootstocks (Lombard and Westwood, 1976; Fallahi and Larsen, 1984).
- Fallahi and Larsen (1984) also found fruit of Bartlett grown on this rootstock were high in N, P, K, Mg, Mn and Fe.

Recommendations for nitrogen, potassium and calcium management:

- Leaf (especially bearing spur and shoot) and fruit levels of single nutrients should be obtained in spring before any fertilizer applications, examined as nutrient ratios, rather than single nutrients, and the recommended optimal leaf levels be used with caution in judging whether N, K or Mg should be applied.
- If ratios are high (Ca low in relation to N, K and/or Mg), and no other deficiency symptoms for N, K or Mg are apparent, any further application of N, K or Mg may be contraindicated.
- Uptake of Ca is often difficult and its mobility in the tree limited. There is no assurance that soil applications of Ca will be effective. Ca is needed most by the fruit in the earliest stages of fruit development. Tissue analyses as early as possible, once fully-expanded leaves and small fruit drop has occurred, shoot and bearing spur leaves, and small fruit, should be sampled for nutrients. Leaf Ca level is **not** indicative of fruit Ca level.
- Early N absorption (May to August) is negatively correlated to fruit quality (Yamazaki and Mori, 1960); there are no significant correlations with late N application (Sept to October). Nitrogen moves in the xylem like Ca and can compete with Ca for cation exchange sites, inhibiting Ca uptake and movement at a time when N is detrimental to fruit development (and enhances vigor) and when Ca is needed for fruit development. N builds up in developing fruit tissues faster than Ca does, enhancing the N/Ca imbalance that promotes fruit disorders (Shear, 1974).
- The strong recommendation of replacing the soil calcium nitrate application with foliar Ca treatments should be considered. Ca foliar applications at high frequency (up to six applications) and higher rates of Ca should be considered, as long as fruit finish is not problematic (this is, however, a possibility).

- Consider eliminating annual N application unless visual deficiency symptoms are apparent; alternatively, apply N in fall.
- When an imbalance of K/Ca or (K+Mg)/Ca is found in any leaf or fruit tissues sampled in spring, consider no K application, or consider fall soil application of K in place of K fertigation in spring so that the ratio imbalance will be less likely to affect fruit.
- Although we have focused here on the rootstock in this trial, there have been several studies done on the various rootstocks used for European pear varieties; many of these have pronounced tendencies to take up more or less of essential nutrients and this fact can lead to fruit quality problems for many other rootstock/soil combinations. The infrequent occurrence of *P. calleryana* in California pear culture doesn't preclude similar problems in other rootstocks.
- Nor should the conclusions here be dismissed for fruit that are not going to be stored long-term (which is less common for 'summer' pears such as Bartlett). Ripening problems started showing up with the first phase of postharvest ripening (6 days after harvest).

2010 October tissue analyses

These samples were taken after harvest but prior to soil K treatment in the 'Soil' K plot. The main difference that one would expect would be those differences in nutrient uptake and utilization by the crop as a function of 'location'.

- Shoot and bearing spur leaves were consistent indicators of K by 'location'
- There was little consistency between this sampling time and the April and July sampling times with respect to 'location' or tissue types
- Other than to illustrate nutrient cycling through the growing season, this sample evaluation did not provide any clear answers for the main questions to be answered in this trial.

2011 April tissue analyses

- Differences among plant parts within a given K treatment were more numerous than between K treatments for a given plant part.
- Fertigation and Soil K treatments appear to have equalized the nutrient levels generally between these treatment 'locations', overcoming most differences that were likely due to soil/water changes within the orchard and the uptake responses of the rootstock to those changes.
- Shoot leaves were the best tissue to sample at this timing for K uptake differences by K treatment, although this applied only to comparing tissue types for a given nutrient by K treatment.
- One important trend that was observed–bearing spur leaves in the Soil treatment showed the lowest ratios of nutrients where Ca was part of the ratio (N/Ca,

(K+Mg)/Ca and K/Ca). This is of value as an indicator of potential problems for fruit quality due to low Ca. Not only is it important that this tissue was the only tissue showing this consistent relationship, the fact that the Soil K treatment improved this ratio suggests that where fruit quality problems that implicate these balances are found, postponing K application to postharvest may be of benefit.

Differences among plant parts within a K treatment:

Fertigation plot, nutrients where significant differences were found (No differences between were found for N, Ca, Mg, Mn, Fe or any nutrient ratios):

- Fruits were among the highest accumulators of nutrients, especially in P, K, S, Zn and Cu
- Shoots were the lowest accumulators of P, K, B and Cu and the highest accumulator of N/K
- Bearing spurs tended to be lower accumulators, although not as low as shoots
- No clear pattern was seen for non-bearing spurs; non-bearing spur leaves hand the lowest N/K ratio

Soil K plot, nutrients where significant differences were found (No differences among plant parts were found for P, Ca, Zn or Mn):

- Shoots were high accumulators of N, K, Mg, Fe and Cu and low accumulators of B
- Bearing spurs were high accumulators of Mg, S, B, and N/K and low accumulators of K and Cu
- Non-bearing spurs were high accumulators of Cu and low accumulators of Mg, B and N/K
- Fruits were high accumulators of Mg and low accumulators of N, K, S, B, Fe, Cu and N/K
- Overall, leaves were poor indicators of fruit nutrient level, with shoot leaves more or less the opposite extreme for most nutrients where differences were found.

In common between K treatments:

- No differences among plant parts for Ca or Mn, but five instances of nutrients where one K treatment showed no differences but the other did show differences among plant parts for nutrient levels suggests the influence of local soil/water conditions on uptake by the rootstock influencing nutrients and their distribution in the tree.

Conclusions:

- When comparing tissue types for sampling, within a given K treatment plot, the greatest differences in nutrient level extremes were found between fruit (generally high levels of nutrients where there were significant differences) and shoot leaves (generally low levels of nutrients). Spur leaves from bearing and non-bearing spurs tended to show generally moderate levels of nutrients.

- If a single tissue type were collected, and conclusions drawn from that tissue analysis for nutrient status in the tree, misleading information would result.
- However, if only shoot leaves and fruits were collected, the conflicting information on nutrient levels would not provide the grower with useful information, without some other previously developed information, such as fruit nutrient levels and their predictability for potential quality problems.

Comparison to nutrient values in April 2010:

- Virtually no similarities regarding differences by location (2010) or K treatment (fertigation vs soil K) by plant part nutrient level,
- The exception of nutrient ratios by 'location' (K treatment plot) **in bearing spur leaves**. These similarities were:
    - Higher N/K in Soil than Fertigation
    - Lower Soil than Fertigation for (K+Mg)/Ca, K/Ca and N/Ca

Conclusion: Together with the April 2011 finding that bearing spur leaves in the Soil treatment showed the lowest ratios of nutrients where Ca was part of the ratio (N/Ca, (K+Mg)/Ca and K/Ca), these data suggest that where fruit quality problems that implicate these balances are found, postponing K application to postharvest may be of benefit. This result was consistent both before and after differential treatment.

Important similarity between October 2010 nutrient levels and April 2011 levels:

- Shoot leaves in Soil K plot had higher levels in October 2010, before soil treatments with K and still had higher levels than the Fertigation plot in April 2011.

Conclusions:

Generally, there were more differences than similarities between treatments when comparing either April, 2010 vs 2011 or October, 2010 vs April, 2011, suggesting that the Soil K application in November, 2010 was altering the nutrient level differences from 2010 to 2011 and equalizing them with the Fertigation treatment applied in Spring, 2010, as well as potentially overcoming some of the differences due to 'location' (i.e. soil/water differences and interactions of these with the rootstock).

<u>2011 July tissue analyses</u>

Adequacy in nutrient levels, 2010 vs 2011:

- Shoot leaves, both treatments were low in:
    - 2010 K
    - 2011 K, Ca, Mn, Cu
- 2010, Shoot leaves Fertigation treatment: Ca, Mn
- 2010, Shoot leaves Soil treatment: N, P

- 2011, Non-bearing spur leaves: K, Mg, S low in both treatments

Conclusions:

- Soil K in fall may have helped to overcome mid-summer low levels of N and P found in 2010 (Soil plot).
- Shoot and non-bearing spur leaves in 2011 showed common inadequacy in only K. For Ca, Mg, Mn, S and Cu, only one or the other leaf type showed inadequate levels by standard recommendations for that leaf type.
- No deficiency symptoms were seen, and trees had good vigor. Given the previous year's results, low Ca would be the only nutrient of concern.

Differences by K treatment within plant part type:

- No nutrient balances were different by treatment
- All leaf types analyzed showed higher Fe in the Fertigation plot than Soil plot
- Where differences existed by K treatment, the Fertigation treatment was higher than Soil for all but B
- K treatment by fertigation increased levels of N, P, Fe, S in some leaf types but not others.
- Higher N prior to harvest could be problematic for fruit, although nutrient balances were not different by treatment.

Differences among plant parts within a K treatment:

- Treatment differences across plant parts were numerous and highly significant in all nutrients we tested.
- Shoot leaves had highest levels in almost all cases.
- It was not possible to conclude that one leaf type was better to sample than another based on this data alone.

<u>Harvest 2011</u>

- Fruit were slightly larger in general with Fertigation, although differences were very small
- A slightly higher number of #1 fruit were found in the Soil treatment <u>as a percentage of the overall harvest</u>, but the difference was small; yield of #1 fruit was higher in the Fertigation treatment in actual numbers.
- Yields tended to be higher overall for the Fertigation treatment, however, irregular numbers of limbs and actual canopy consisting of those limbs varied from tree-to-tree.

A better comparison would be a percentage of change per treatment over the trial period (see final yield calculations at end of 2012 harvest data).

2011 September tissue analyses

- Soil > Fertigation for Mn for both shoot and bearing spur leaves; no other K treatment differences were found.

Differences among plant parts within a K treatment:

- Bearing spur leaves > shoot leaves for Ca, Mg in both Fertigation and Soil treatments
- Bearing spur leaves > shoot leaves for Zn in Soil treatment and for Fe and Cu in Fertigation treatment
- Shoot leaves > bearing spur leaves for: N/K, (K+Mg)/Ca, K/Ca, in Fertigation treatment.
- Shoot leaves > bearing spur leaves for: Mg/Ca and N/Ca in both K treatments.

Conclusions:

- Within a given plant part, K treatment was not different except for Mn. Any leaf type sampled would have given similar results for treatment differences.
- However, bearing spur leaves and shoot leaves showed significant differences in how much of given nutrients they accumulated; these differences occurred often in both treatments.
- In most cases where nutrient level differed by leaf type, bearing spur leaves had higher levels than shoot leaves.
- Because bearing spur leaves accumulated higher levels of Ca than did shoot leaves, ratios with Ca were lower for spur leaves than shoot leaves, across both K treatments.
- It is possible that higher accumulation of Ca by bearing spur leaves may indicate higher accumulation of Ca by subtending fruit, but that is not conclusive without sampling fruit tissues.
- July values were not good predictors of September values; this was also the case in 2010.

2012 April tissue analyses

Differences between 2011 and 2012 results: Fruit: Ca, Fe and Mn were extremely low and Mg much lower in fruit than in April 2011

Differences by K treatment within plant part type:

- Nutrient values for April 2012 were not different by treatment, for a given plant part. Therefore, data analyses were repeated with treatments combined and 'replicate' term now a combination of the 'treatment' location and original 'replicate' (now a total of 16 'replicates', instead of 8 replicates x 2 treatments).
- Shoot leaves highest in N, P, S, B, Cu, N/K

- Bearing spur leaves highest in K, Ca, Mg, Zn, Mn, Fe
- Non-bearing spur leaves highest in Ca, Mg, N/K
- Fruit highest in P, (K+Mg)/Ca, K/Ca, Mg/Ca, N/Ca and lowest in N, Ca, Mg, S, Zn, Mn, Fe
- The fact that there were no treatment differences may be due to light cropping in the 2012 year, with lower than usual nutrient demand at this time shortly after small fruit drop.
- It was not possible to conclude that one leaf type was better to sample than another based on this data alone.

<u>July 2012 tissue analyses</u>

Differences among plant parts, comparison to April 2012 values and adequacy levels:

- Nutrient values different by treatment were found for shoot leaves (Fe) and bearing spur leaves (Mn) only. Therefore, treatments were combined for data analyses, as for April data. All nutrients were different among plant parts and highly significant, except for Cu.
- Shoot leaves highest in N, P, S and N/K. Both April and July high values, therefore were in N, P, S and N/K.
- Bearing spur leaves highest in K, B, Zn, Mn, Fe and (K+Mg)/Ca. Both April and July high values, therefore, were in K, Zn, Mn and Fe. Perhaps more importantly, bearing spur leaves were <u>lowest</u> in N, P, Mg and N/K. Maturing fruit may have been preferentially pulling these nutrients from adjacent bearing spur leaves.
- Non-bearing spur leaves were highest in Ca, Mg, S. Both April and July high values, therefore, were in Ca and Mg. The fact that growing fruit (April) were lowest in Ca, Mg and S and that the non-bearing spur leaves are highest in these same nutrients at the 'standard' sampling time for deficiencies may indicate that non-bearing spur leaves are not the best indicators for nutrient status in fruit quality considerations.
- Inadequacy based on published values (van den Ende and Leece, 1975) for mid-summer non-bearing spur leaves were found in K (non-bearing spur and shoot leaves), N (bearing spur leaves) and Ca (bearing spur and shoot leaves). Of these the lowest was Ca in shoot leaves, which may be a matter of concern when young fruit are also low, as in 2013.
- Both shoot and non-bearing spur leaves were in the range of K/Ca that indicates moderate to high chlorosis (Lindner and Harley, 1944), due to low K status in these leaves.
- Leaf nutrient values were not expressed in harvest fruit quality however low K and Ca in leaves in July and low Ca in fruit in April may have been indicators of potential postharvest disorders. This would be a good research area to pursue.

Harvest, 2012, and Combined yields, 2010-2012

- No differences in yield or fruit quality were found in 2012.

- When comparing yields from 2010 + 2011, 2010 + 2011 + 2012, the Fertigation treatment had higher yields per tree (combined limbs) than the Soil treatment. However, this difference could be explained by differences in number of limbs and volume of canopy found tree-to-tree within and between treatments.
- A better measure of treatment effect on yield would be to compare the percent change in yield over time from the same limbs and trees. There was no significant difference between treatments from 2010 to 2011. Although there was no significant difference from 2010-2012 in cumulative percent increase in yield, there was a numerical difference with the Soil treatment greater than the Fertigation treatment.

Overall conclusions for Elliot II trial, including nutrient management recommendations:

- This orchard was adequately fertilized, despite apparent deficiencies indicated in leaf samples.
- The potential for nutrient imbalances that can affect fruit quality, especially with storage, was amplified in the area where the soil changes occurred.
- Sampling in early spring and mid-season, especially of small fruit in spring, provided good prediction of potential for fruit disorders.
- Tissue analyses should be interpreted with caution with respect to applying nutrients, (especially N and K), that can exacerbate potential for disorders. Nutrient balances should be calculated and used to assess need for fertilizers before application.
- In order to avoid potential for fruit quality disorders Fall application of K is advised and applications of Ca in Spring should be considered as a foliar application, without added N. Any N application should be considered for fall, to reduce the likelihood of nutrient imbalances for fruit quality when those are indicated by early season tissue analyses.
- No adverse effects on yields or fruit size were caused by either K treatment, therefore, the main consideration in this orchard is reduced exposure of the fruit to N and K preharvest, and consideration of foliar Ca preharvest in numerous applications using forms that are reduced risk for fruit finish.

INTRODUCTION

Review of Historic Nutrition Management Guidelines

Review of current nutrient management recommendations and the historic development of both monitoring system and those recommendations was appropriate for trial design and interpretation of results. Defining an appropriate balance of nutrient required for optimum growth and cropping requires a way to monitor tissue nutrient levels and tree uptake and responses to available nutrients.

Development of nutritional recommendations in California

Lindner and Harley (1944) found that Bartlett pear trees grown on calcareous soils could overcome severe chlorosis with iron citrate injections; tissue iron levels did not change with treatment, but Ca content rose, and the ratio of K/Ca dropped as chlorosis was overcome.

Proebsting (1944, 1953) started developing N and P requirements for California Bartlett pear; normal growth and yield occurred despite wide differences in N and P content in mid-summer basal shoot leaves (N = 1.8 – 2.65% and P = 0.2 – 0.29%). In 1961 Proebsting concluded an extensive statewide series of 5-year trials in 15 orchards, mainly aimed at determining N requirements. Basal leaves from shoots were collected throughout the growing season; reported mid-summer N values ranged from 1.6-2.2% in unfertilized trees and 1.9-2.6% in fertilized trees. Some trees showed no change in tissue N when starting as unfertilized and then fertilized over the 5-year period; Proebsting interpreted this result as failure of uptake or translocation without logical explanation, and that no physiological response in cropping or growth could be expected without change in tissue levels. Throughout Proebsting's decades of investigation he remarked on pear's insensitivity to N, in particular, but also to P, unlike the other fruit tree species with which he worked. In six of 15 orchards, Proebsting found increased yields and in these cases basal shoot leaves had increases in tissue N of 0.2-0.9% with final tissue N ≥ 2.1%; those orchards without improved yields had tissue N = 1.9-2.4%. Proebsting concluded that <u>leaf analyses have a limited utility in predicting response of pear trees to fertilization. Probably response could be expected with leaf nitrogen below 1.7%. Between 1.7% and 2.2%, local influences would determine whether or not a response would be obtained, and the rate of application necessary to secure such a response would be uncertain. Above 2.2%*. any response to applied N* would be unlikely</u>. <u>No single criterion seemed adequate as a guide to fertilization. Vigor, leaf color, and production, combined with leaf analyses, should give substantial indications of the likelihood of response, but multi-year field trials would still be necessary for a final answer as to whether or not to apply nitrogen, and the rate if applied.</u>

Studies from 1965 to 1966 (Hewitt, 1967; Hewitt et al., 1967) in commercial orchards in the Delta and North Coast Districts and a greenhouse sand culture trial found little tissue level response to a wide range of applied N. Fruit quality at harvest and after storage was unaffected by level of applied N and no correlations with leaf N content were found. <u>Fruit set, however, was highly correlated with leaf N measured in June or September; critical values of 2.0-2.3%N in June and 1.7-2.0%N in September could be inferred from this result</u>.

These studies concluded that pear trees would not respond to additional applied N if leaf levels in June were 2.3% or greater. Inadequacy was demonstrated by reduced yields due to poor fruit set. Hewitt et al. (1967) concluded, however, that adequacy due to applied N amount would be difficult to measure, since tissue N levels were not indicative of applied N level or uptake.

Yields for European pear in California tend to be much higher than when nutritional requirements were first developed (Lindner and Harley, 1944; Hewitt, 1967; Beutel, Uriu and Lilleland, 1978, 1983) and while it is logical that more crop ‘removes’ more N, higher N also tends to decrease storage life of pome fruits and much more of the current pear crop is produced for fresh market than in the past (typically ~40% of current crop is processed for canning and juice). Rootstock is a significant contributing factor to vigor and yield, in an inverse relationship (Reil and Howell, 1998). Rootstocks also vary in their ability to take up specific nutrients. Any comprehensive nutrient management recommendations should account for these differences. A rootstock that imparts high vigor may also require more a higher level of N as 'adequate' for good fruit set. Site specificity, especially with respect to soil texture and rootstock, will ultimately dictate the long-term cropping potential nutrient needs of an orchard. Review of grower fertilizer management practices based on 2008 (Sacramento Delta or 'Early' District) and 2010 (North Coast or 'Late' District) practices and current recommendations of optimum timing, form, and amount of N to produce pears to today’s standards was a starting point for this study. Details of the 2008 and 2010 California Pear Advisory Board (CPAB) funded studies are at the end of this report for informational purposes.

N fertilization recommendations for California European pear trees have been modified from 1991 (75 to 125 lb actual N per acre per year ($\#N_{act}$/A/yr); UCANR Publication 3340 Integrated Pest Management for Apples & Pears) to 2007 (2 lb actual N per ton of crop per acre per year; UCANR Pear Production and Handling Manual, 2007). Tissue N critical value (CV) is 2.2%, adequate N range is 2.3-2.6%. Tissue analysis standards in California are based on leaves from non-fruiting spurs as these 'are easiest to collect and give the most consistent results.' (Beutel et al.,1983; UCANR IPM for Apples and Pears manual, 1991). CV's are for the June-July period, but 'samples may be taken in August or September if interpretation of results is adjusted for seasonal effects by subtracting 0.2% from June/July levels of N and K' (Beutel et al.,1983).

Vigor control is difficult with high water tables and high vigor leads to higher fire blight susceptibility; fireblight management by pruning reduces tree canopy, bearing capacity and is high-cost. BMP should reflect N partitioning spatially in tissues and temporally during the growth and rest cycles to minimize over-usage, increased vigor, and ground water leaching. There is no 'one size fits all' approach to fertilizer management—some growers take the approach that inputs can be reduced, or fertilization eliminated on an annual basis if no adverse effects result (reduction in yield or fruit quality, lack of vigor or tree deficiency symptoms) and tissue levels don't indicate inadequacy. Other growers tend to perceive reduction in N as a risk for reduced crop load and fruit size and that critical values (CV's) established when tonnage was lower and most fruit went to processing (thus fruit size was less important), or fresh fruit were not stored, should be re-evaluated. California's Delta trees are 30 to 100+ years old, may retain tissue nitrogen for years without applied N (1997-2000 unpublished study, Ingels), and are intensively farmed in a highly sensitive waterway.

Reconsideration of Current Guidelines and Recommendations for Future Research

Tissue nutrient sampling considerations and reported critical values (CV), Table 1

Shoot leaves have been sampled for nutrient levels in many pear-producing areas of the world, and while current UC recommendations apply to nutrient levels in non-bearing spur leaves, much of the underlying research conducted in California prior to 1983-2007 depended on nutrient values from shoot leaves. Research findings from outside of California amount to a considerable volume of information and it could prove valuable to be able to utilize this information more fully if nutrient standards for California were in line with much of the rest of the world.

Why have researchers concentrated on shoot leaves?

- Most deficiency symptoms for nutrients are recognized in shoot leaves, both for non-bearing and bearing trees (e.g. K deficiency shows first in shoot basal leaves or is most pronounced in mid-shoot leaves, N deficiency in older shoot leaves while N is mobilized to younger leaves, Mg deficiency shows first in older basal shoot leaves or fruiting spur leaves).
- Shoot leaves may be sampled from both young, nonbearing and mature trees
- Terminal, extension shoots grow throughout the season, thus providing a source of both older (basal) leaves and newer, mid-shoot leaves for comparison.
- Unlike non-bearing spurs whose leaves are fully mature soon after bloom or bearing spurs whose leaf nutrient levels may be more reflective of the subtending fruit load than the overall tree status, leaves from actively growing shoots may better reflect both the overall tree 'seasonal' demand and immediate nutrient 'profile'.
- It is important to distinguish, however, that there tend to be two distinct populations of vegetative shoots on Bartlett trees among those that first 'break' in spring flush – some shoots stop growing at ~3-6" in length while others may grow for up to 3 months (Glozer, unpublished data). Shoots that are to be sampled from first flushes must be among the latter group, which cannot be predicted at the start of budburst.

- Secondary flushes of vegetative extension shoot often occur from late May-early June in the Sacramento Delta, and possibly elsewhere if deficit irrigation cannot be utilized. These shoots should be used for leaf sampling only with the understanding that they are distinct from the first flush extension shoots.

Non-bearing spur leaves are those currently used for California sampling, although the reason for the departure from the use of shoot leaves in historic pear research is not clear. It may have been the choice of those writing the recommendations for California fruit trees in 1983 (Beutel et al., 1983) to apply a single standard to as many species as seemed appropriate, since this publication was comprehensive for temperate tree fruit species commonly grown in California at the time. In the 1983 recommended practices for leaf analysis (Beutel et al., 1983) spur leaves were to be used for pear and all stone fruit species but peach, for which basal to mid-shoot leaves were recommended as peach bears primarily on current season expansion shoots. Other than stating that 'Leaves from non-fruiting spurs are easiest to collect and give the most consistent results', these authors did not cite past research or other justifications for this choice.

- Non-bearing spur leaves complete growth shortly after bloom and no additional leaves arise on these spurs in the current year. By using these leaves only, it may be more difficult to determine 'real-time' status of nutrient mobilization (or the lack thereof for non-mobile nutrients) due to seasonal fertilizer applications, growing fruit, or fruit removal (thinning, harvest). These leaves represent a relatively static population and may reach a senescent state earlier than shoot leaves.
- Although basal shoot or bourse (bearing spur) leaves also represent a relatively static 'older' population of leaves, these leaves are still part of a more dynamic tissue 'unit'. Fruiting spurs are highly dynamic for both source (photosynthesis) and sink (developing fruit) functions. Vegetative shoots grow for a longer period of time than do non-bearing spurs and are both sources (photosynthates) and sinks (rapid vegetative growth) for nutrients. Since nutrient flux is a function of both source and sink relationships, dynamic tissue units may be more representative of changing nutrient status than the relatively non-dynamic, non-fruiting spur.
- Comparisons to nutrient levels or recommendations developed for pear outside of California are difficult, since this leaf type doesn't appear to be used for nutrient profiling elsewhere.

  Pear leaf analyses in Washington State are mid-shoot http://hort.tfrec.wsu.edu/Orchard/leafanly.html as are those in Oregon http://extension.oregonstate.edu/douglas/sites/default/files/documents/hort/osupa.pdf
- Ease of comparison to other spur-bearing tree crop species for nutrient management does not justify 'lumping' pear with the stone fruit species, particularly as pear is markedly insensitive to N and bourse spurs are different from stone fruit spurs.

Bearing spur leaves have not been reported in the literature reviewed as sampled for nutrients in pears, however, fruiting spurs in other tree crop species have been sampled for these kinds of studies and have shown relevance to changing nutrient status in relation to cropping and fruit quality.

- It is possible that pear researchers have chosen not to use bearing spur leaves in studies that concentrated on nutrient requirements for growth alone in comparisons between young tree and mature tree requirements (young trees aren't bearing), or in potted tree trials where bearing trees on standard rootstocks would have been too big and cropping atypical.
- Bearing spur leaves may more accurately reflect nutrient status for subtending developing fruit demand than vegetative shoot leaves as bearing spur leaves are most likely those providing 'first available' nutrients to developing fruits (as shown in nutrient radio-labeled studies in some fruit species).
- If bearing spur leaves are used for nutrient studies in pear, the type of leaf should be very specific, as bourse spurs in pear have bourse leaves and bourse shoot (the vegetative shoots that arise on the bourse itself) leaves. As such, the bourse is actually a 'mixed' shoot with both reproductive and vegetative function.

N management for vigor

Vigor control by reduced N inputs is ineffective in Bartlett pear (Ramos et al., 1994; Ingels, unpublished data). Our trials substantiated previous findings. Pear's insensitivity to and/or limited of uptake of N does not warrant use of the UC recommendation for N usage by shoot growth, except in conditions where water management makes this a viable option.

Overall nutrient management strategy considerations and recommendations

While the current recommendations are a reasonable starting consideration for growers, in that these recommendations stress monitoring orchard N status regularly with tissue N of 2.2% as the critical level and that N usage be at a relatively conservative rate based on current cropping, this should be used as part of a larger strategy that also uses historic orchard bearing capacity, local soil, water, tree characteristics, early crop load estimation, annual orchard fluctuations in cropping (hence nutrient drain and return cropping), visual leaf symptoms, shoot growth, and fruit quality/storage goals. It would appear from the grower surveys that these strategies are all being used to some extent, with growers particularly aware that there is no 'one size fits all' answer to nutrient management.

The results of the trials reported here tend to support the conclusions of Proebsting (1961) after his decades of work with California Bartlett pears (and other tree crop species), and with Weinbaum et al. (1992): 'The use of leaf analysis to diagnose tree nutrient status is based on the assumption that leaf N concentration increases with soil N availability. If tree N status is low, leaf N concentrations increase significantly with the application of fertilizer N (examples given for almond and apple).' Numerous studies have shown a limited range in leaf N and P in European pear with a wide range of applied fertilizers, indicating inefficiency in uptake and long-term retention of nutrients when deficiency is not present.

Nutrient adequacy in pear can be long-lived without annual fertilizer applications. Studies in pear and other temperate tree fruit species (Taylor et al., 1975 Niederholzer et al., 2001, to cite two in which extensive whole tree tissues were evaluated for nutrients, carbon and carbohydrates) have found that tree nutrient adequacy creates a situation in which trees tend not to take up additional nutrients; indeed, 50% of tree leaf N is typically remobilized to storage tissues at the end of the growing season, representing at least 80% of the total N storage capacity of the entire tree. This amount of N already present in the tree, cycles into growing tissues in spring and recycles into storage tissues in fall, prior to leaf drop. In trees with adequate N at the end of the growing season, this is sufficient nitrogen to provide early spring growth without fall application, until the next spring application.

- Leaf analyses have a limited utility in predicting response of pear trees to fertilization, except under nutrient deficient conditions.
- Probably response could be expected with leaf nitrogen below 1.7% for mid-summer value for basal shoot leaves. Between 1.7% and 2.2%, local influences would determine whether or not a response to applied N (increase or decrease in amount) would be obtained, and the rate of application necessary to secure such a response would be uncertain. Above 2.2%*. any response to applied N* would be unlikely. (Proebsting, 1961).
- Because so many factors remain uncertain orchard trials must be carried on for several years, to determine the best solution for a particular situation.
- No single criterion seems adequate as a guide to fertilization. Vigor, leaf color, and production, combined with leaf analyses, should give reasonable indications of the likelihood of response, but field trials would still be necessary for a final answer as to whether or not to apply nitrogen, and the rate applied.
- Bartlett pear, in particular, tends to be insensitive to N. Fruit set, and therefore crop load, is affected when leaf levels (mid-summer basal shoot, mid-season shoot or non-bearing spur) are below 2.1-2.2% N. These values apply to the current season nutrient drain, thus return bloom and the following year's fruit set. Seedless fruit set in European pear varieties (parthenocarpy) tends to be improved by higher N levels (but not excessive N), and in the case of d'Anjou, heavy pruning. Heavy pruning in Bartlett decreases fruit set while moderate pruning improves set.
- Moderate N rates tend to improve yields by improving fruit set (1.5 $\#N_{act}$/tree/yr) while high N rates may reduce yields but improve fruit size (4 $\#N_{act}$/tree/yr; Westwood et al., 1964).

- Nutrient balance or interactions among nutrients should be assessed as part of specific site management decisions. In some cases, nutrients show an inverse relationship, for example:
    - N and P – an increase in N depresses P tissue levels regardless of the phosphate fertilization. Sod culture tends to elevate tissue P and depress tissue N (Kenworthy, 1950; Boynton, 1954); sod also improves water penetration and soil aeration (UCANR IPM for Apples and Pears manual, 1991).
    - Ca and K – an increase in K depresses Ca, tending to produce chlorosis and fruit disorders.
    - Nutrient optima should reflect current strategy of maximum yield and 'target fruit'. High nitrogen is considered detrimental to fruit quality, as a balance among nitrogen, calcium and potassium, particularly.
    - Nutrient balances and imbalances may be a result of differences in rootstocks and their uptake and utilization of nutrients, or as a result of inappropriate application of nutrients – often in a 'blend' where one or more nutrients is not needed and may antagonize uptake or utilization of another nutrient
- Spring leaf sampling allows preharvest fertilization choices more effectively than sampling shortly before harvest for in-season adjustments. Leaves for spring sampling should be first fully-expanded shoot leaves (terminal or mid-shoot) or bearing spur leaves collected after small fruit drop and before any large-scale nutrient applications have been made for an early season nutrient profile.
- If crop load is at the heavy end of historic yield and spring shoot, non-bearing or bearing spur leaf N< 2.6%N consider half of an annual rate of 2 #N_{act}/ton/A, using historic high yield figures as a reference. Retest the same leaf types (youngest, fully-expanded shoot leaves or non-bearing or bearing spur leaves) postharvest. If leaf levels are< 2.0%N for any leaf type, apply an annual half-rate of 2 #N_{act}/ton/A, using current year yield figures as a reference.
- If crop load is at the moderate to low end of historic yield and spring shoot, non-bearing or bearing spur leaf N ≥ 2.6%N consider no application of N in the current year. When tree N is adequate, additional applied N will be of no benefit.
- If mid-summer shoot or non-bearing spur levels for N are below 2.1-2.2% additional N application is warranted postharvest, so as to avoid potential negative effects on current season fruit quality, particularly for postharvest ripening and storage purposes.
- Amount of N to apply if deficiency is indicated will vary depending on the local conditions; a range of N need for cropping may be estimated from the UC recommendation of 2 #N_{act}/A/ton of crop, as well as the estimate of N removal by crop for Bartlett pear (Weinbaum et al., 1992) recommended to avoid over-fertilization:

for 23-30 tons/A yield, 1.3 $\#N_{act}$/ton or 26-38.5 $\#N_{act}$/A is removed by the tree

This estimate is based on tissue analysis of all parts (including endocarp, pericarp, and seed) of fruit grown and harvested under semi-commercial conditions in the Pomology Dept. orchards, Univ. of California, Davis. The difference between these two recommendations is the amount of N needed for tree maintenance and vegetative growth and does not take into consideration local variables such as sod or clean floor culture.

- Adequacy levels may not have much relevance without several years of 0 N applied, as pear is generally tolerant of very low to negligible levels of applied N for extended periods, i.e. tree and soil reserves may be adequate. The N content of mature deciduous fruit trees may be two to three times greater than N taken up annually from the soil (Weinbaum; unpublished data).
- True inadequacy may take several years to develop and a critical level for a given tissue (leaf type, in this case), should be correlated with reduced yield and poor fruit quality.
- Foliar applications that do not compromise fruit quality or produce leaf burn should be considered for improved uptake.
- N requirement in pear is due more to a range of environmental and physiological conditions than N application, specifically, presence of competing plant species (weeds or sod), shallow or poorly drained soil (which sod culture can improve), poor soil type and historically weak, chlorotic trees, individual tree vigor, and cropping. Reasons for nutrient content fluctuations are not always clear but excessive cropping clearly reduces K, increases Ca (as does lime-induced chlorosis; Lindner and Harley, 1944) and Mg with little effect on micronutrients.
- Although orchard yields are most often expressed on a ton per acre (or metric ton per hectare) basis, a better measure of cropping potential is that of yield efficiency (cropping efficiency), which is largely a function of fruit set and final fruit size. This measure takes into account not only the area in which that crop is produced, but also the tree density, hence the cropping potential of the trees in that orchard, which is affected by planting density (thus availability of essential nutrients, water, light and inter-tree competition). For example, three orchards of the same variety, rootstock, soil type and the other fixed conditions, but different tree spacings and all producing 25 tons/A:

tree spacing in-row x between rows (feet)	trees/A	yield (tons/A)	yield efficiency
8x17	320	25	0.08
10x20	218	25	0.11
11x22	180	25	0.14

The highest density planting would have the lowest efficiency rate of yield. While this is simplistic, given the range of variability in all the important orchard factors, it is a method of comparing across those factors. Nutrient management on a per acre basis is insufficient; recommending 2 #N_{act}/A/year of orchards of different spacings is also simplistic. Ideally, recommendation revisions for BMP should review the literature of research already performed on pear that expresses cropping differences with N application and/or tissue levels for examples of yield efficiency at different spacings or on a per tree basis. Some such references are included in the literature section of this report. However, a grower can certainly estimate this on his own, using his historic yield records for a given orchard and that orchard's spacing, with the most conservative N fertilization program that gave the multi-year yields that are reasonable for his orchard. The grower would then calculate the N rate per tree from the N rate per acre and use that figure for N management. The same formula could be applied to any of the nutrients that are indicated as necessary for a given orchard, realizing that in California, most soils and rootstocks do not exhibit many nutritional deficiencies.

Table 1. Comparison of some published critical values (CV; nutrient level below which deficiency is found) of nutrients for European pear, by tissue type (shoot or non-bearing spur leaves) and timing in the cited source. 'Shoot' leaves are from 'extension shoots' or 'terminal shoots' – i.e. vegetative shoots of average vigor, growing several inches to feet in current season. Non-bearing spur leaves are from spur-bearing trees.

	% Dry weight					ppm					
	N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Shoot (mid-shoot leaves; mid-summer, Australia; van den Ende and Leece, 1975)											
Excess	>3.5	>0.30			>0.95						
High	2.8-3.5	0.21-0.30	>2.0	2.2-3.7	0.51-0.90	>2600			121-200	>200	21-50
Optimum	2.3-2.7	0.14-0.20	1.2-2.0	1.5-2.1	0.30-0.50	1700-2600	20-40	20-50	60-120	60-200	9-20
Low	1.8-2.2	0.10-0.13	0.7-1.1	0.8-1.4	0.13-0.29	1000-1600	10-19	10-19	25-59	<60	5-8
Deficient	<1.8	<0.10	<0.7	<0.8	<0.13	<1000	<10	<10	<25		<5
Shoot (mid-shoot leaves in August, Oregon; Hart et al., 1997)											
Adequate	2.1 - 2.5	0.10 - 0.14	>0.9			>1500	30 - 80	>17			
Non-bearing spur leaves (July, California; Beutel, Uriu and Lilleland, 1983)											
Adequate	2.3 - 2.8	0.1 - 0.3	>1.0	>1.0	>1.0	>2500	21 - 70	>18	>20		>4
CV	2.2	0.1	0.7	1.0	1.0	2500	15	>18			
Excess							80	18			
Non-bearing spur leaves, August – September (postharvest), California. Values 0.2-3% lower than July values are considered adequate. (Beutel, Uriu and Lilleland, 1983)											
K/Ca range for moderate to high chlorosis in pear leaves, type unstated = 0.98-1.2 (Lindner and Harley, 1944)											
Mg/Ca > 2 increased risk for iron chlorosis (Elkins, 2000); non-bearing spur leaves											
High K/Ca in pear fruit tissues from fruit with black-end disorder; 5 (peel) 13.1 (flesh) black-end fruit; normal range 0.7 (peel) 11.9 (flesh). Ingels and Card, 2005											
Na in excess over 0.25%, Cl in excess over 0.3%; UCANR IPM for Apples and Pears manual, 1991.											

We have the historic information and current recommendations; why is this project relevant at this time?

In-depth studies of fertilizer need and usage over the last 40-50 years have often been in response to the variability in grower fertilizer management, the perception on the part of researchers that a better understanding of fertilizer management is needed, and in response to current conditions (fertilizer price spikes, public and agency focus on reduced and/or differently-managed fertilizer use, concerns about water quality and fertilizer runoff, horticultural management of pathology and pests). Recent studies of nutrient management or a nutritional role in pear horticultural problems in California include K/Ca balance in black-end fruit disorder (Ingels and Card, 2005), tissue insensitivity to N levels (Ingels unpublished study 1997-2002; 0N vs 90 $\#N_{act}$/A/yr), and nutrient management of iron-chlorosis (Elkins, 2000).

In 2009 we initiated a CPAB-funded study to compare 'High N' and 'Low N' orchards, to develop a basis for re-examining N management in California European pear. Because pear trees may respond gradually to changes in applied nutrients (Proebsting, 1961; Raese, 1996; Ingels, unpublished data), inducing deficient or excessive nutrient levels over the period of the one-year pilot study or this three-year project trial was not possible; a more practical approach toward comparing N requirement and management was to identify and use orchards with existing ‘low’ and ‘high’ N practices for cropping and vigor control. Because growers have changed many practices to obtain higher yields and 'target' fruit for non-processing purposes and higher profit margins, we wanted to focus on questions of fruit quality in addition to general orchard responses. For this reason, we used an orchard with low N input and a strategy in place for manipulating K treatments (fertigation vs soil applications).

When seeking CPAB input for funding proposals to do the 'pilot' study in 2009 and the grower survey in the North Coast District, following pertinent concerns were expressed by the CPAB Research Board:

- A project that evaluated a single 'High N' orchard and a single 'Low N' orchard, comparing tissue nutrient profiles of various tissue types and the orchards' cropping did not seem robust enough to provide enough information to comfortably make recommendations about revising or developing new N fertilization practices.
- Where will tissue N be measured? (i.e. in which tissue(s)?)
- Growers would be interested in being able to determine N levels earlier in the year. Would different tissue types work?
- How does this survey relate to the Sacramento Delta survey that was done last year?
- A sample survey based on a regional perspective, rather than a phone survey might be a better approach.
- We need to know how much NO is released for sustainability purposes.

<u>Clearly there is still 'need to know' a great deal about nutrient management in California pears and the impacts that nutrient levels have on the 'bigger picture' of managing for disease and sustainability.</u>

Work Description, Results, Conclusions and Discussion

Data analyses

The data analysis for this report was generated using SAS© software, Version 9.2 or 9.3 of the SAS System for Windows. Copyright © [9.2 released 2008; 9.3 released July 2011] SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA. Treatment effects for were evaluated using Student's t-test (two levels of treatment or some other factor compared), Proc GLM (General Linear Regressions) when comparing more than two 'levels' of comparison (e.g. shoot vs non-bearing spur vs bearing spur leaves) with means separation by Least Means Squares (LSM), Duncan's Multiple Range Test (DMRT) or Tukey's Studentized RangeTest (Tukey's); Proc Mixed was used for Mixed Linear Model Regressions estimation of fixed effects of 'treatment' or 'plant part' when 'replicate' (a 'random' effect) was a significant source of variation in General Linear Regressions; means separation with Proc Mixed was by Least Squares Means. Normality was evaluated with Proc Univariate and correlations were made with Proc Corr. Stepwise multivariate analyses were conducted to evaluate the influence of 2010 April and July tissue nutrient levels on fruit firmness effects in the Postharvest study. All percentage data were arcsine square root-transformed for analyses.

Sampling practices in common among trial orchards

Samples were obtained from the oldest trees in each orchard (i.e. not from interplants), representative of that population of trees in the treatment area and avoiding atypical canopy structure or other obvious problems. In each of the trial orchards subsampling within a replicate block for each treatment was made on at least one group of four trees (a 'tree quad') that was as closely associated physically as possible, with as similar an overall structure and cropping potential as possible. Tissue samples of buds (2009) and leaves of a given type were combined for each tree 'quad', with not less than 10 leaves collected from each individual tree. When prunings were collected for comparison of vigor by N treatment, the prunings from each 'tree quad' were combined and weighed.

Spur buds (in pilot study, beginning of 'budswell', March 2009), bearing spur leaves and non-bearing spur leaves were sampled from spurs no more than 4” in length, at approximately 6’ above ground level, on all sides of the canopy and at the canopy periphery for maximum light exposure. Terminal shoot buds were selected at the tips of 1-year old wood, in similar locations as the spur samples.

Sampling terminal vegetative shoot buds and spur buds prior to bloom provides an early picture of N status; sampling the same buds in fall prior to leaf drop shows both N status due to cropping and N status due to longer-term postharvest N uptake than mid-summer sampling of leaves would. Terminal shoot buds were selected rather than mid-shoot buds because terminal buds represent the next year's extension shoots that will break (mid-shoot buds may or may not be released from dormancy and axillary inhibition). When terminal shoot leaves were sampled in fall, sample time was after terminal bud set but before initiation of leaf fall.

Terminal shoot leaves (for all shoot leaf collections 2009-2012) were chosen for sampling, rather than mid-shoot leaves because the terminal leaves most closely correspond to the same growing points as the terminal shoot buds collected in 2009 for baseline data. Furthermore, nutrient analytical sampling procedures recommended by the UC ANR Analytical Lab are for 'young' leaves, so as to avoid potentially senescing leaves and to assess 'real time' nutrient levels for mobile and non-mobile nutrients. All shoot and spur leaves included the petiole. When small fruits were sampled for analyses, the sample timing was immediately after small fruit drop to ensure that all fruits were viable; fruit size range = 18-24.

Leaves, fruits and buds were washed in a mild soap solution, rinsed and dried in an oven at ~55 °C. All samples were ground and analyzed at the UC ANR Analytical Lab. All nutrients were expressed on a dry weight basis (% or ppm). Total N was analyzed by the Kjeldahl method; all other methods of nutrient analyses may be found at http://anlab.ucdavis.edu/analyses/plant.

Background of Trial Orchards

A practical approach was adopted in which we used three 'Bartlett' orchards with existing conditions that allowed manipulation of nutrients. These orchards represented the majority of Sacramento Delta 'Bartlett' orchards with a range of yields of (20-32 ton/A/yr), tree age, rootstock, soil and growing conditions. All growers of the trial orchards typically sampled annually for tissue, irrigation water and soil nutrient profiles. Orchards 'Elliot I' and 'Elliot II' were on Sutter Island and 'McCormack' was on Twin Cities Road, halfway between Interstate 5 and the Sacramento River.

Elliot I ('High N' vs 'Low N' = 60 or 120 #N_{act}/A/yr vs 0 N)

The range of 'High N' treatment above represented an annual adjustment to N fertilizer rate over the three-year trial period, beginning with the historic rate of ~120 #N_{act}/A/yr vs a 'UC recommended' rate for the high end of historic yield in this orchard (~30 tons/A, so 60 #N_{act}/A/yr). a higher rate than current recommendations, but the historic N application in this orchard prior to 2008. While 120 vs 60 #N_{act}/A/yr was the intended comparison in the first year, crop loss due to hail damage in late spring led to reduction for the orchard at large to 60 #N_{act}/A/yr, thus we down-sized the 'Low N' treatment to 0N. In subsequent years we returned to 120 #N_{act}/A/yr for 'High N', but remained at 0N for 'Low N' using this level as following the UC recommendations (0N for vegetative growth exceeding 12" per year).

This orchard was part of a pilot study in 2009 as the 'Low N' orchard in comparison with a 'High N' orchard. The orchard was planted about 100 years ago, probably on 'Winter Nelis' rootstock at an original spacing of 16'x17'and interplants have been continually added for approximately 30 years, as trees were removed, and to decrease the in-row spacing to 8' x 17' (320 trees/A with interplants). The orchard was adjacent to the Sacramento River on Columbia series silty loam soils. Yields have been typically 23-30 tons/acre prior to 2009; 20009 crop was 25 t/A. Total applied N for 2006 and 2007 was 123 $\#N_{act}$/A/yr, as 62 $\#N_{act}$/A calcium nitrate in spring + 1.4 $\#N_{act}$/A/yr as KNO3 applied in spring (split at first cover or first codling moth preventative, and approximately 2 weeks later), and 60 $\#N_{act}$/A from ammonium sulfate in fall. In 2008 the fall application was eliminated as a cost-saving measure fuel to fertilizer price spikes. Leaf analyses at the end of June 2008 showed 3.04% N, 0.17% P, 1.25% K, 1.69% Ca, 0.42% Mg, 24 ppm Zn, 24ppm Mn, 112 ppm Fe, 10 ppm Cu, 28.1 ppm B and 0.011% Na. Of these, only the N was excessive by UC standards. Soil analysis at that time showed that pH was 6.33, nitrates 19.1 ppm, ammonium 1 ppm, and of other nutrients tested, only Mg exchangeable appeared excessive at 588 ppm. 'Low' to 'very low' soil nutrients included soluble K, Ca, Mg, and B. Irrigation was by micro-sprinkler and scheduling was a combination of water budgeting and current season growth and cropping needs.

Elliot II ('Budgeted' Low N and Nutrient Balance Effects on Fruit Quality and Cropping)

This was our test orchard for N:K:Ca effects on fruit quality and cropping, as well as 'budgeted' low N. We compared the grower's 'traditional' K application (300# K_2O=90 #Kact/A/yr applied to soil in fall) to K fertigation ($K_2S_20_3$, three equal applications during fruit development=84 $\#K_{act}$/A/yr). Responses to treatment were evaluated at harvest and postharvest.

The orchard was planted in 1927 and original trees were on *P. calleryana* rootstock at a spacing of 11' x 22' with mature interplants. There was a soil type change just outside of the area of the trial. Immediately west of the trial area, but within the same orchard and nearer the Sacramento River was Soil type 222 'Scribner clay loam'. Within the trial area was Soil type 141 ' Egbert clay'. The area of soil change and the diagonal placement of the fertigation system across the orchard necessitated a specific trial layout (Figure 1).

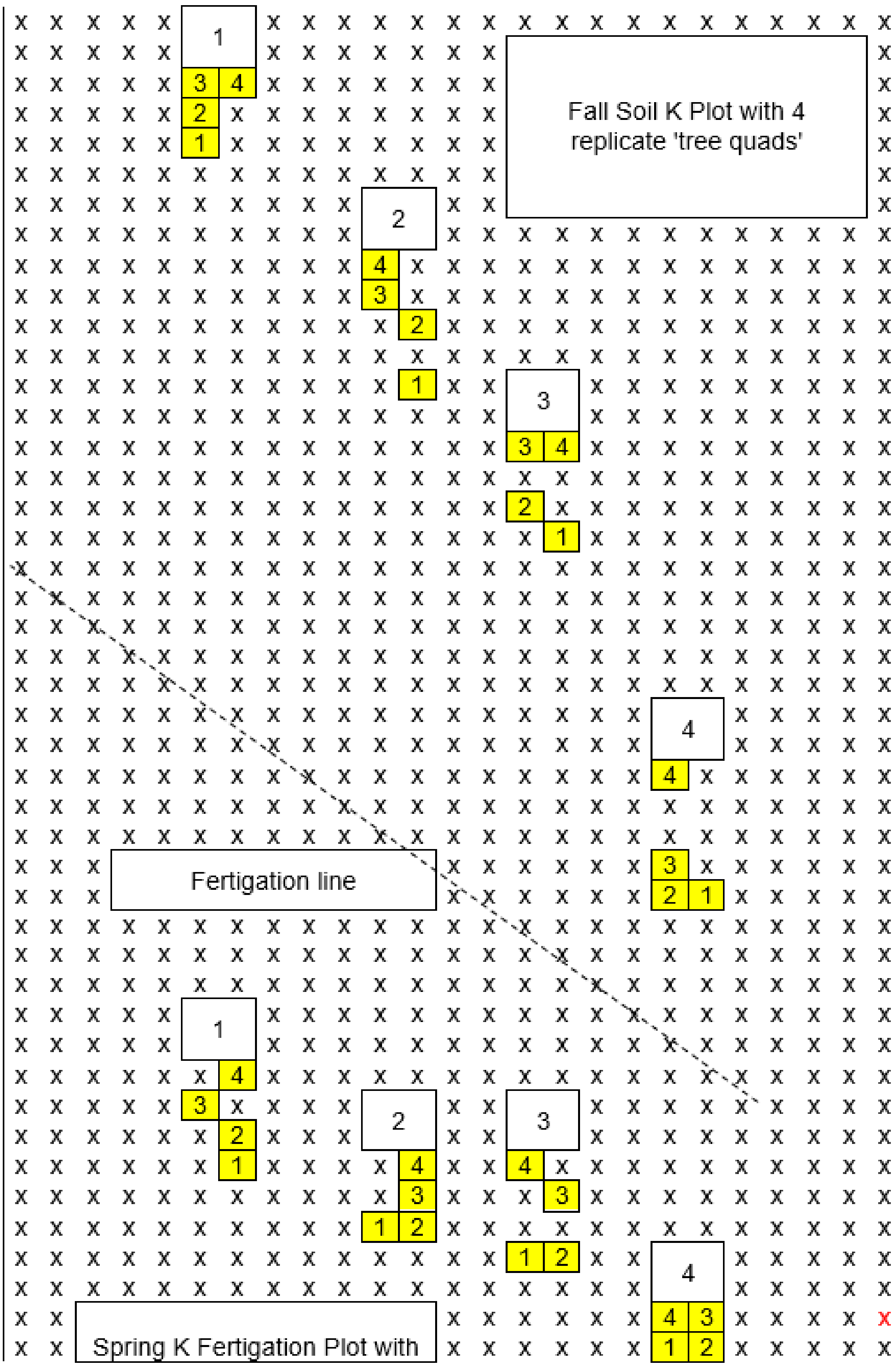
Until 2007 the typical fertilizer program was 100 $\#N_{act}$/A/yr immediately after harvest and a fall application of potash (application of K was 'budget dependent'). In 2007 and 2008 no fertilizer was applied as a cost-saving measure. Beginning in 2009, the block was fertigated in spring with KMend (potassium thiosulfate $K_2S_20_3$), soluble potash (K_2O) at 25% and S at 17%, by weight. Irrigation and fertigation flow rate via this system was ~0.1"/hr. In addition, 200 lb $Ca(NO_3)_2$ was broadcast twice in spring (early May, end of June; 62 $\#N_{act}$/A/yr + 84 $\#Ca_{act}$/A/yr) and a small amount of urea was added to fireblight sprays (final $\#N_{act}$/A/yr from urea 0.7-2.76 $\#N_{act}$/A/yr) for 'fruit finish'.

Differential K treatments for this trial were:

- Spring K fertigation with KMend ($K_2S_20_3$)=84 #Kact/A/yr x three equal applications, May, June1 (84 $\#K_{act}$/A/yr)
- Soil K application of 300 #/A/yr K_2O=90 $\#K_{act}$/A/yr in November

The grower's choice to change K application form and timing was to allow discretion on a 'crop level' basis. The spring application allowed adjustment of fertilizer quantity based on current season crop load, was applied during the time of greatest demand by growing fruit and was consistent with protocols for better 'fruit finish' and storage longevity. The grower reported that he saw little to no reduction in vigor and no loss of yield or fruit quality from 2007 onward. Typical yield has been 25 tons/A, regularly cropped, with the yield varying year-to-year by no more than 1-2 tons. Fruit quality has been consistent and without disorders. The fruit has not been 'hard to size' and was picked twice for size.

Figure 1. Trial plot map for **Elliot II**. Dashed line shows position of fertigation line; solid line shows approximate transition of two soil types; within the trial area was soil type 141 ' Egbert clay' and soil type 222 'Scribner clay' was just outside the trial plot, nearer the Sacramento River.


Fall Soil K Plot with 4 replicate 'tree quads'
Fertigation line
Spring K Fertigation Plot with

McCormack ('High N' vs 'Low N' customized annual program to equalize differences within the orchard); customized BMP

The total orchard size was ~23 A and the size of our trial plot was approximately 3 acres comprising 16 rows. Orchard rows had a N-S orientation with a 'drop' towards the south half, with higher water table resulting in increased vigor, earlier harvest, heavier crop load and larger fruit than in the north half. Tree spacing with interplants was 20' x 10' (218 trees/A) and the rootstock for original trees was *Pyrus ussuriensus*, an Asian pear rootstock. Recent management changes (flood changed to solid set sprinkler irrigation, increased N and better pruning) have increased yields from 20-23 ton/A/yr to 30-32 ton/A/yr. Both halves of the orchard received a total of 152#N_{act}/A/yr until 2010. Prior to harvest, starting 2010, a revised fertilization program was begun to equalize fruit development rate, cropping and vegetative vigor between the N and S halves of the orchard. The annual amounts of N were adjusted by the grower, depending on his evaluation of current cropping conditions, maintaining a high differential between the two halves of the orchard.

Irrigation May-June was part of the fertigation schedule; postharvest irrigation was at approximately 3-week intervals until leaf fall, excluding any significant rainy period. Irrigation scheduling was a combination of ET estimation and current season growth and cropping needs.

Nutrient analyses in 2009 from an area of the orchard near the trial area and before the beginning of this trial had the following results (mid-summer): Leaf nutrient levels were 2.68% N, 0.15% P, 1.18% K, 1.79% Ca and 0.40% Mg. Of these values, P and Mg were deficient (CV's 2.3-2.7% and 1.2-2%, respectively). Soil nutrient levels (ppm) were NO_3-N 14.7, NH_4-N 2.0, P_2O_5 55, K_2O (exchangeable) 578, K_2O (soluble) 18.1, Ca (exchangeable) 3190, Ca (soluble) 42, Mg (exchangeable) 1100 and Mg (soluble) 18.2.

Work Plans, Results, Conclusions and Recommendations, by Orchard Trial

Task 1: Determine the relationship between seasonal tissue N partitioning and concentration and tree productivity and growth (i.e. reassess the currently-accepted leaf N critical values, timing of sampling and tissues tested; effects on vegetative and reproductive growth). **Elliot I**

Elliot I ('High N' vs 'Low N' = 60 or 120 #N_{act}/A/yr vs 0 N)

Treatment regime: Since this trial was initiated as a CPAB-funded pilot study in 2009, preparatory for this FREP project, the treatments were begun in 2009, as was the data collection, both of which are summarized here.

The CPAB pilot study was begun Spring, 2009 as a complete random block design with 2 treatments (0N, 60N) x 3 replicate blocks of 4 rows each (comprising the grower's usual harvest pattern of 4 rows harvested into common bins) and 4 subplots of 4 trees each from which subsampling for tissue analyses and vegetative growth measurements were made. The subplot trees were chosen from among the original orchard trees, adjacent to each other and as uniform as possible with respect to canopy size and trunk diameter. Each replicate consisted of ~200 trees (oldest trees and interplants); tree number was adjusted based on tree size, using the largest, oldest trees as a standard. This adjusted tree number (~160-180 trees per rep) was used for yield calculations.

Buds and leaves were combined from the 4 subplot trees for analyses (buds not sampled after 2009). KNO_3 was applied at 5#/A April 14 and April 28, (13.7% N) = 1.4 #N_{act}/A, applied in blight sprays and/or at ‘first cover’ with codling moth spray; for purposes of suppression of European red mite nymphs.

The rest of the fertilization in 2009 was as $Ca(NO_3)_2$ twice with 200 lb per application (mid May, end of June) = 62 #N_{act}/A + 84 #Ca_{act}/A. Yields were estimated using an adjusted value for number of trees, based on canopy size and cropping of heaviest bearing trees in the trial orchard. The rating system was on a scale of 0 to 3, with 0 = no tree (to aid in adjusting tonnage per acre yields based on tree spacing/trees per acre) or a young interplant with 10 fruit or less, 1 = tree of low vigor and low number of fruit, 2 = a tree of mid-level vigor and medium number of fruit, 3 = a fully filled canopy of the size of the largest trees in the orchard overall.

In October, 2009, the trial comparing the orchard 'standard' N input (122#N_{act}/A /year) to the reduced rate (62#N_{act}/A /year) was initiated. Thus, the 'Low N' treatment had 2 seasons of lower N rate by the 2010 trial year and the 'High N' treatment had 2009 'Low N' + 2010 'High N' applications (Table 2). No Spring N was applied to the 'Low N' treatment during 2011 as the orchard received hail damage in late spring and the grower decided that expenditure of fertilization throughout the orchard as a whole was unwarranted. In 2011 and 2012 we compared 60 #N_{act}/A to 0#N_{act}/A prior to harvest, with an additional 60 #N_{act}/A applied in early November for the 2012 year (to 'High N' treatment

Subtask 1.1.2 Elliot I orchard, seasonal tissue N partitioning and concentration

In 2009 following N partitioning into buds in spring and fall and leaves during the growing season was begun (Figure 2). Three sample timings (late April, preharvest July and pre-leaf fall, September-October) for N content of different leaf types (shoot, bearing and non-bearing spur) has shown the following (Tables 3 and 4):

Partitioning into different plant organs (vegetative vs reproductive), illustrating both movement of N into storage tissues and probably removal of N with cropping. In March 2009 spur buds were much higher in N content than shoot buds as reserves were mobilized for flowering and fruiting. N was lower and below the critical value for bearing spur leaves (both orchards) after harvest, while N of shoot and vegetative spur leaves was much higher and adequate.
As differential treatments continued, in 2010, significant differences between high and 'Low N' treatments were found within bearing spur and shoot leaf types (higher in 'High

N' treatment) and levels were much lower in bearing spur leaves than shoot leaves just before harvest.

Shoot leaf and bearing spur leaf N levels were higher in spring and preharvest in the 'High N' treatment in 2010 with no difference in non-bearing spur leaves in April and no difference among the other leaf types in either 2010 or 2011 Fall (Table 4, 2011 and 2012 only). In April 2011, only the bearing spur leaves of the 'High N' treatment had significantly higher N, but by preharvest the shoot leaves and non-bearing spur leaves of this treatment had higher N and the bearing spur leaves did not. In April 2012, both shoot leaves and bearing spur leaves of the 'High N' treatment had significantly higher N, with no differences in the July collection among leaf types or between treatments.

In April 2011 N treatments showed significantly different tissue N levels for bearing spur leaves only, and significant differences for shoot and non-bearing spur leaves in July only; in all cases the 'High N' treatment caused higher tissue N.

In April 2012, both shoot and bearing spur leaves showed significant differences in tissue N ('High N' had higher tissue N); no other significant differences were found in 2012.

Conclusions: The most consistent pattern of N content differences year-to-year has been significantly higher N in fully-expanded shoot and bearing spur leaves in spring, prior to spring N applications, where trees have received a fall application of N, and preharvest in summer. Non-bearing spur leaves showed differential N treatment response in tissue N only in 2011 mid-summer. No levels were inadequate in any tissues in spring or summer (preharvest), even when 0N was applied. Where treatment differences occurred within a given tissue, the 'High N' treatment consistently produced higher tissue N.

A main purpose of this study was to re-examine the current recommendations for BMP, tissue N analysis being an important component of that. Because the results year-to-year did not indicate a definitive pattern, we analyzed the data for 2011 by a Mixed Linear Regression Model, allowing the 'replicate' factor to be 'random'. Strong 'replicate' effects can obscure 'treatment' or 'plant part type' effects.

Table 5: Replicate effects were highly significant for April and July tissue analyses, but not for September. Nitrogen treatment level was also highly significant for April and July, less so for September. Leaf type sampled was highly significant for all collection timings. An N treatment x replicate interaction of weak significance was found only for the April timing.

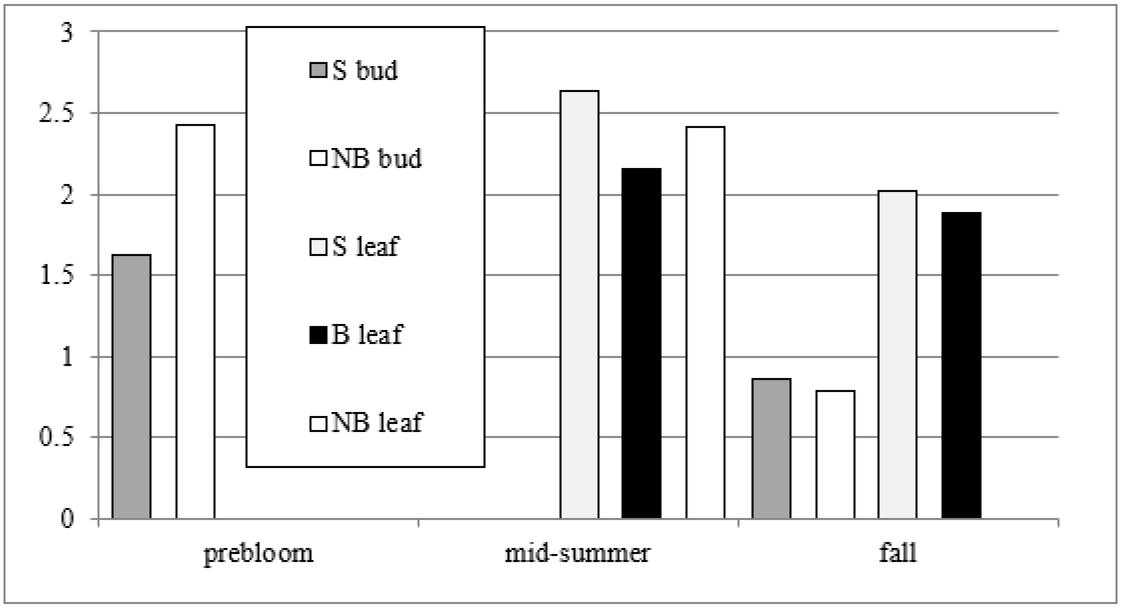


Figure 2. Partitioning of N in 2009 at **Elliot I** into plant parts (S = shoot, NB = non-bearing spur, B = bearing spur); fertilization was 63 #N_{act}/A/yr, applied as KNO_3 + CA $(NO_3)_2$

Table 2. N Fertilization practices, **Elliot I**.						
		#N_{act}/A/yr			Forms of N and timing of application	
		Spring	Fall	total	Spring	Fall
2007		63	60	**123**	CA $(NO_3)_2$	$(NH_4)_2SO_4$
2008		63	0	**63**	CA $(NO_3)_2$	
2009	rest of orchard	63	60	**123**	[x] KNO_3 + CA $(NO_3)_2$	$(NH_4)_2SO_4$
	trial area	63	0	**63**	KNO_3 + CA $(NO_3)_2$	
2010	High N	0	60	**60**	No spring N due to hail damage	$(NH_4)_2SO_4$
	Low N	0	0	**0**		
2011-2012	High N	60	60	**120**	KNO_3 + CA $(NO_3)_2$	urea
	Low N	0	0	**0**		

[x] Spring KNO_3 was applied at 5#/A (13.7% N) = 1.4 #N_{act}/A, applied in blight sprays and/or at 'first cover' with codling moth spray; for purposes of suppression of European red mite nymphs. The rest of spring fertilization as $Ca(NO_3)_2$ twice with 200 lb per application (mid May, end of June) = 62 #N_{act}/A + 84 #Ca_{act}/A.

Table 3. **Elliot, I** tissue N for 2009 and 2010. 'High N' (123 #N/A/yr) vs 'Low N' (60 #N/A/yr) was applied in 2009. Tissue N critical value is 2.2%, adequate N range is 2.3-2.6%, using non-bearing spur leaves for analyses in mid-summer. Buds collected in Spring, 2009 were from spurs no more than 4" long, ~6' up in canopy on all sides of the tree, outer canopy (i.e non-shaded).

2009	Shoot terminal bud	Spur bud	Significance
March 9	1.62 b^x	2.43 a	***

	Shoot leaf	Spur leaf		
		Non-bearing	Bearing	Leaf type
July 7	2.64 a	2.41 b	2.15 c	***

	Leaf type		Bud type			
	Shoot	Non-bearing spur	Shoot	Non-bearing spur	Leaf type	Bud type
Oct 1	2.02 a	1. 89 b	0.85 c	0. 79 c	*	***

2010 Comparison of High and 'Low N' within leaf type for treatment effects

#N$_{act}$/A/yr: 'High N' 122, 'Low N' 62		Shoot leaf	Spur leaf	
			Non-bearing	Bearing
April 19	High N	2.99 a*	2.86	2.64 a*
	Low N	2.85 b	2.84	2.54 b
July 12	High N	2.76 a***		2.17 a*
	Low N	2.61 b		2.09 b

Harvest occurred after July tissue sampling. 60#N applied September 22 as ammonium sulfate to 'High N' treatment only. For October timing, 'Low N' had received 0N for 12 months.

Oct 6	High N	2.19		2.08
	Low N	2.14		2.02

^{x} Means separation within columns and measures by LSMeans 5% level. Different letter following value denotes significant difference; *, ** and *** = significance at 5%, 1% and 0.1%, respectively.

Table 4. **Elliot I**, 2011-2012 tissue N. All harvests occurred after July sampling 'High N' treatment received 60# N/acre in spring-summer (preharvest) as KNO_3 + CA $(NO_3)_2$ and 60# N/acre in fall as urea; 'Low N' treatment received 0#N/acre 2010-2012.				
2011 Comparison of High and 'Low N' within leaf type, by date for treatment effects				
		Shoot leaf	Spur leaf type	
			Non-bearing	Bearing
April 29	High N	3.08	2.98	2.59 a*
	Low N	2.97	2.92	2.49 b
July 18	High N	2.80 a**	2.47 a**	2.25
	Low N	2.68 b	2.39 b	2.20
Sept 27	High N	2.13		1.98
	Low N	2.07		1.92
2012 Comparison of High and 'Low N' within leaf type, by date for treatment effects				
		Shoot leaf	Spur leaf	
			Non-bearing	Bearing
-April 30	High N	3.23 a**	3.06	2.58 a*
	Low N	3.03 b	2.95	2.44 b
July 10	High N	2.89	2.51	2.15
	Low N	2.78	2.52	2.14
[x] Means separation within leaf type and date by Student's T-test, 5% level. Different letter following value denotes significant difference; *, ** and *** = significance at 5%, 1% and 0.1%, respectively.				

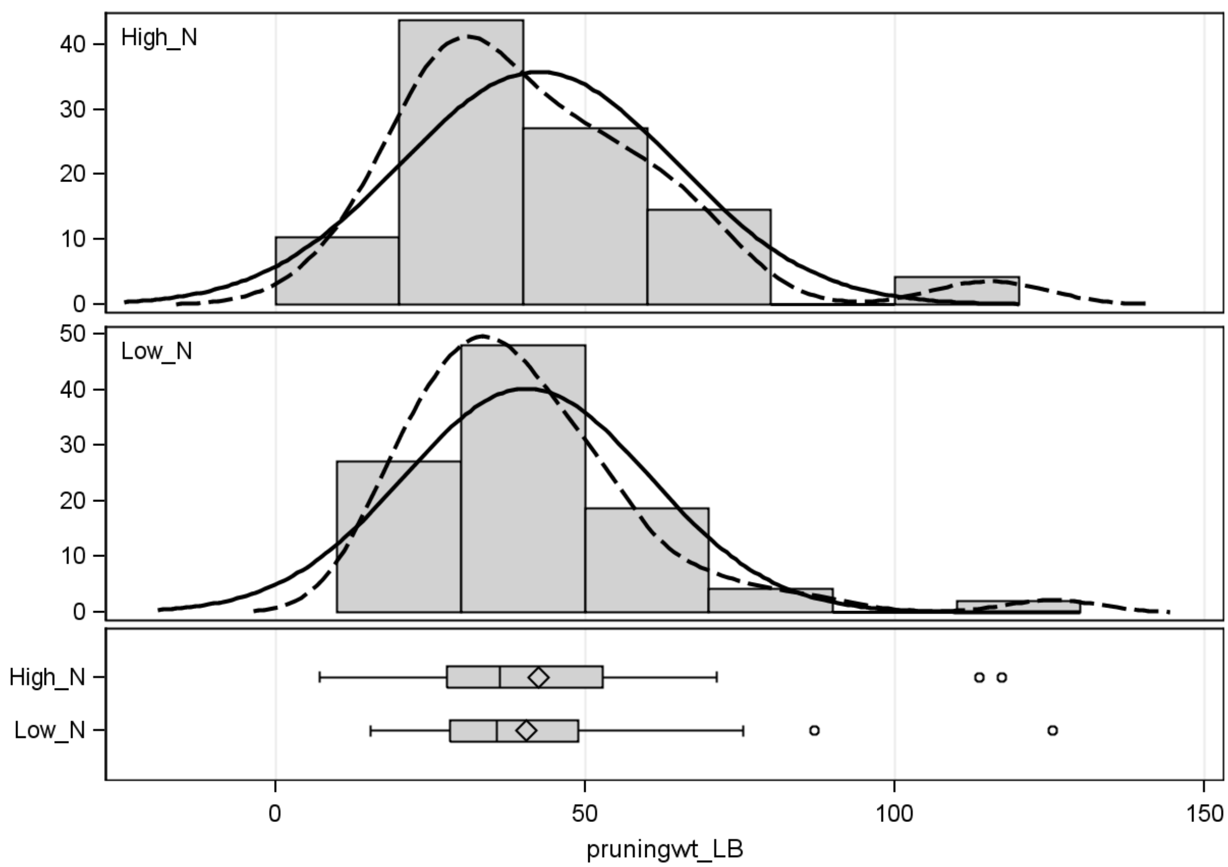
Table 5. Mixed linear regression analysis; effects of differential N program for **Elliot I**, 2011. September samples did not include non-bearing spur leaves. Significant effects shown as shaded.			
	April	July	September
Nitrogen level	0.0014	0.0002	0.0163
Replicate block (consisting of 4 'tree quads')	<.0001	<.0001	0.0869
Tree quad	0.0864	0.2591	0.1773
Leaf type	<.0001	<.0001	<.0001
Nitrogen*rep	0.0423	0.8959	0.5065
Nitrogen*leaf type	0.7584	0.5327	0.7399

Subtask 1.1.3 Elliot I orchard treatment effects on vegetative and reproductive growth

Subtask 1.2 and Task 2: Compare 'Low N' with 'High N'; compare typical and reduced N to validate recommended N management and the possibility of customizing BMP based on tissue levels, fruit quality and crop load

Vegetative growth: When pruning weights collected in February 2011 were compared for 'High N' and 'Low N' treatments made in 2010, there were no differences between treatments (Figure 3). A weak, negative correlation was found between pruning weights collected in 2010 and, subsequently, April tissue N level of non-bearing spur leaves for 2010 (Figure 4). Thus, when tissue N levels were lower, vegetative vigor was also slightly decreased. No other correlation was found between pruning weights and April tissue N and the lack of response in vegetative growth measured in February 2011, to differential N treatments from 2009-2010 was consistent with numerous other studies in European pear showing a general insensitivity to N level.

Figure 3. Distribution of pruning weights, February 2011 for vegetative growth at **Elliot I** in 2010. There was no difference between 'High N' and 'Low N' treatments.



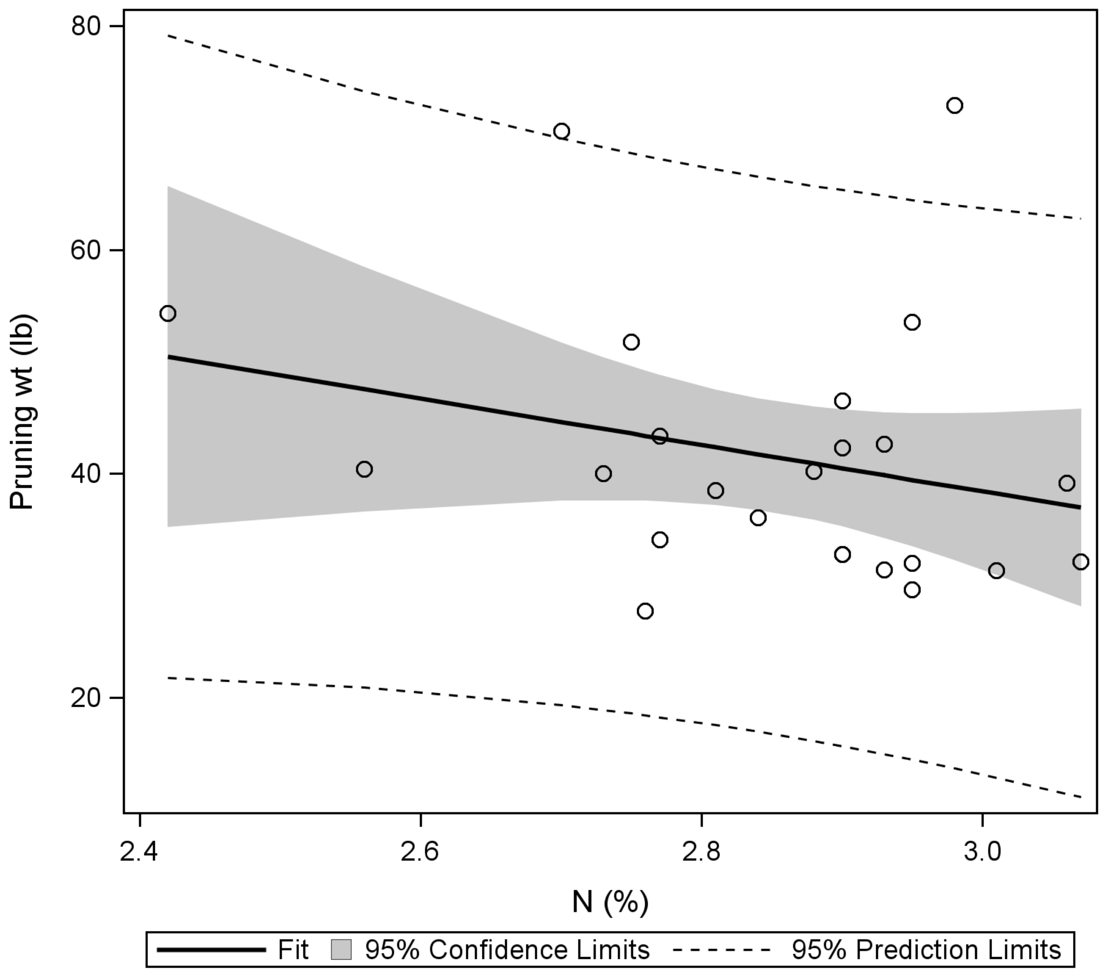


Figure 4. Correlation between dormant pruning weights, February 2011, **Elliot I**, and non-bearing spur leaf N, April 2010. R-Square = 0.0698.

Reproductive growth and yield

2010 Table 6: No treatment differences in yield or fruit quality were found except for the percentage of #1 fruit, which were significantly more (~9% more) in the 'High N' treatment. Although the yield (tons/A) were numerically lower (14.3 vs 17.3 tons/A) for the 'High N' treatment, replicate differences within each treatment were such that significance of treatment differences may have been obscured. A Sacramento Delta European pear orchard as old as **Elliot I** has had decades of tree loss and replant, as well as extensive scaffold reduction due to fire blight pruning and natural attrition. While we attempted to equalize these differences by rating trees and adjusting the tree number per replicate block, there was no perfect system to completely eliminate tree-to-tree variability such as presented here. It is typical for trees to show great variability across numerous phenological factors. Nonetheless, we can feel certain that lower yields in the 'High N' treatment contributed to significantly higher numbers of larger fruit. With yields per acre fairly low in 2010 due to hail damage, yield did not appear to limit fruit size overall as both treatments had a high percentage of #1 fruit.

2011 Table 7: As in 2010, despite numerical yield difference by treatment, there were no significant differences. Treatment differences for fruit size were highly significant (0.1% level), even when the replicate effect was analyzed independently by the sub-sampling for size grade performed throughout the ongoing harvest.

2012 Table 8: The first harvest showed a higher percentage of the crop sized as #1 fruit for the 'High N' treatment, and significantly larger #2 fruit in the same treatment. No differences in fruit quality were found in the second harvest, and no other statistically significant yield or quality differences were found as a result of differential N treatments. Numerically, however, as in the two previous years, the 'High N' treatment tended to result in increased fruit size while decreasing overall yields per tree and acre (the case in 2010 and 2012, but not in 2011). Cumulative tonnage per acre for 2010-2012 was 63.7 ('High N') vs 67.6 ('Low N').

Discounting the crop loss year of 2010 (a large portion of the crop was lost to hail damage), cumulative yields per acre for 2011 + 2012 were 49.5 (High N) and 50.3 (Low N), or ~25 tons/A/year. Yield efficiency (yield on a per tree basis, 320 trees/A), High N yield efficiency for 2011 was 0.09, for 2012 was 0.065 and the average for the two years combined was 0.077 at 120 #N_{act}/A/year. The yield efficiencies for the Low N (0N) treatment were: 0.084 (2011), 0.073 (2012) and 0.079 (2011 + 2012). This was the comparison that seems to make the best sense – 0N paid off for this grower these years.

Conclusions:

While the UC recommendations for nitrogen fertilization of 'Bartlett' pear were based, in part, on vegetative growth responses to change in N status, both this study and others (Ramos et al., 1995) indicate that this consideration was not valid at this location.

Where deficit irrigation was possible early in the season, vegetative growth was highly correlated to N status. Our findings at **Elliot I** from pruning weights versus N fertilization level and overall cropping and N fertilization level would indicate that 'Bartlett' pear was fairly nitrogen tolerant. In this orchard, with its particular growing conditions, the grower's current strategy of N management (0-60 $\#N_{act}$/A/yr) appears to be justified. This does not discount the possibility that a different strategy of much higher N might 'pay off' in better cropping and fruit quality (size), however, the grower's past regimen of a 'typical' annual rate of ~120 lb N/A/year would indicate that the bearing capacity of this orchard was relatively maximized with the grower's current strategy.

2007 BMP recommendations for 2 $\#N_{act}$/A/yr would equal 58 $\#N_{act}$/A/yr for the 2011 'High N' yield of 29 tons/A – 120 $\#N_{act}$/A/yr was applied and by the 2007 recommendation, this additional applied N did not improve cropping potential. Since the 'Low N' (0 $\#N_{act}$/A/yr applied) yielded 27 tons/A, the conclusion would be that this orchard had sufficient soil and tree levels of N without additional inputs. Similar conclusions would be drawn for 2012 yields ('High N' = 20.7 tons/A and 'Low N' = 23.4 tons/A) with the same N treatments as in 2011.

Table 6. Yield and fruit quality for **Elliot I**, 2010. Significant hail damage reduced the crop; KNO_3 and $Ca_2(NO_3)_2$ applications did not occur in spring. 60 $\#N_{act}$/A as $((NH_4)_2SO_4)$ was applied Sept. 22. Fruit were harvested in a 'single pick', August 5-6. Yield measures were calculated from an entire block of 4 rows (3 replicate blocks per treatment), harvested into common bins. Yields per acre and per tree were calculated based on 'adjusted' number of trees, accounting for differences in size of interplants and original trees (100+ yrs old). Averages for yields by treatment and replicate block shown.

N level	Fruit wt (oz) for #1 fruit	Count per lb	%Soluble solids	Firmness (lb)	% #1 Fruit	Yield (lb per tree)	Tons/A
High N	7.8 a[x]	2.07 a	11.6 a	29.8 a	79.8 a	179 a	14.3 a
Low N	7.8 a	2.03 a	11.7 a	30.0 a	70.5 b***	216 a	17.3 a

[x] Means separation within columns and measure by Student's *t* test; different letters show significant difference (P = 5%). *, **, *** = Significance at 5%, 1%, and 0.1% levels, respectively. Percentage data means separated based on arcsine square root transformation (actual means shown).

Averages for replicates to illustrate variability due to replicate block.

Replicated block	Lb/tree yield		Tons/A yield	
	High N	Low N	High N	Low N
1	142	268	11.4	21.4
2	166	196	13.3	15.7
3	227	184	18.2	14.8

Table 7. **Elliot I**, harvest, 2011: First harvest on July 25 was a selective pick for size of 2 ½" diameter (#1 fruit); the second harvest, on Aug.10-11, picked and sorted to a minimum size of 2 ⅝" for #1 fruit. 'High N' treatment was 120 #N_{act}/A/yr, 'Low N' treatment received 0N. Yields estimated using an adjusted value for number of trees, based on canopy size and cropping of largest, heaviest bearing trees in the trial orchard.

	First harvest July 25			Second harvest Aug 10-11			Harvests combined	
	Fruit wt (oz)		% #1 fruit	Fruit wt (oz)		% #1 fruit	% #1 fruit	Count/lb
	#1 fruit	#2 fruit		#1 fruit	#2 fruit			
High N	6.3b***[X]	4.4a	88b***	6.8a	3.8a	91a	89b*	2.54b*
Low N	6.6a	4.3a	91a	6. 9a	3.7a	92a	91a	2.46a

	Yield/tree (lb) by harvest			Estimated tons/A yield (lb) by harvest			%Yield as first harvest	% Soluble solids
	First	Second	Total	First	Second	Total		
High N	114a	246a	359a	9.1a	19.6a	28.8a	32.1a	11.6a
Low N	79a	258a	336a	6.3a	20.6a	26.9a	23.2a	11.7a

[X] Means separation within columns and measure by Student's *t* test; different letters show significant difference (*P* = 5%). *, **, *** = Significance at 5%, 1%, and 0.1% levels, respectively. Percentage data means separated based on arcsine square root transformation (actual means shown).

Table 8. **Elliot I**, 2012: Harvest of 'Bartlett' pears. Fruit were sorted to a '#1 fruit' size of 2 ⅝" at the first harvest and sized to 2 ⅜" at the second harvest. All fruit below these size limits were '#2 fruit'. 'High N' treatment was 120 #N_{act}/A/yr, 'Low N' treatment received 0N. <u>Yields estimated using an adjusted value for number of trees, based on canopy size and cropping of largest, heaviest bearing trees in the trial orchard.</u>

	% of total crop as #1 fruit	July 17 harvest: Fruit weight (oz) #1	July 17 harvest: Fruit weight (oz) #2	July 17 harvest: #1 fruit as % of harvest	July 27 harvest: Fruit weight (oz) #1	July 27 harvest: Fruit weight (oz) #2	July 27 harvest: #1 fruit as % of harvest	Count/lb total harvest
High N	79.2a[x]	7.1a	5.4a	68.9a**	7.0a	4.1a	90.4a	2.43a
Low N	74.1a	7.3a	5.2b*	54.3b	6.7a	5.0a	93.4a	2.47a

	% of crop at first harvest	Lb/tree: First	Lb/tree: Second	Lb/tree: Total	Estimated tons/A: First	Estimated tons/A: Second	Estimated tons/A: Total	%Soluble solids: First	%Soluble solids: Second
High N	30.6a	79a	179a	258a	6.3a	14.3a	20.7a	12.6a	13.0a
Low N	27.6a	80a	210a	292a	6.4a	17.0a	23.4a	12.6a	12.9a

[x] Means within columns followed by a different letter were significantly different at *P* = 0.05 by Student's t-Test; *, **, *** = 5%, 1%, 0.1%, respectively. Percentage data means separated based on arcsine square root transformation (actual means shown).

Subtask 1.2 and Task 2: McCormack orchard: Compare 'Low N' with 'High N'; compare typical and reduced N to validate recommended N management and the possibility of customizing BMP based on tissue levels, fruit quality and crop load

As at **Elliot I**, we applied an adjusted value for number of trees, based on canopy size and cropping of heaviest bearing trees in the trial orchard, for estimating yields. The rating system was on a scale of 0 to 3, with 0 = no tree (to aid in adjusting tonnage per acre yields based on tree spacing/trees per acre) or a young interplant with 10 fruit or less, 1 = tree of low vigor and low number of fruit, 2 = a tree of mid-level vigor and medium number of fruit, 3 = a fully filled canopy of the size of the largest trees in the orchard overall. The rating system was applied equally to each half of the orchard

Subtask 1.2.1 McCormack orchard apply treatment regime, Table 9**:** Both halves of the orchard received a total of 152 #N_{act}/A/yr until 2010. Prior to harvest, starting 2010, the orchard program shown in Table 2 was begun to equalize fruit development rate and vegetative vigor between the N and S halves of the orchard. Spring fertigation N was applied throughout the block (irrigation runs E-W), May and June.

The trial design was a complete block in which each treatment was replicated four times, in contiguous rows of ~108-116 trees each, half of which were in the 'North half, low vigor' treatment and half in the 'South half, high vigor' treatment. Each replicate, consisting of four half-rows was harvested into common bins; tissue samples and pruning weights were subsampled from four-tree 'tree quads', trees typical for the replicate in canopy volume (excluding replants) and located as close to each other as possible.

Table 9. Fertilization at **McCormack** orchard in 2010-2012.

2010	
282 #N_{act}/A North half, low vigor trees	Fertigation 6x May-June = 129 #N_{act}/A from CAN-17
	May and June 300 #/A each CA $(NO_3)_2$ = 93#N_{act}/A
	November, MOP (0-0-62): 322 #/A = 200# K_2O/acre = 166 #K_{act}/A + Urea: 130 #/A = 60 #N_{act}/A
129 #N_{act}/A South half, high vigor trees	Fertigation 6x May-June = 129 #N_{act}/A from CAN-17
2011	
313.5 #N_{act}/A North half, low vigor trees	Fertigation 7x May-June = 150.5 #N_{act}/A from CAN-17
	May and June, 300 #/A each CA $(NO_3)_2$ = 93 #N_{act}/A
	November 630 #/A of a blend (11-0-44) = 70 #N_{act}/A
150.5 #N_{act}/A South half, high vigor trees	Fertigation 7x May-June = 150.5 #N_{act}/A from CAN-17
2012	
255 lb N/A North half, low vigor trees	Fertigation 5x May-June = 107.5 #N_{act}/A from CAN-17
	2xin June 200 + 300 #/A CA $(NO_3)_2$ = 77.5 #N_{act}/A
	November 630 #/A of a blend (11-0-44) = 70 #N_{act}/A
107.5 #N_{act}/A South half, high vigor trees	Fertigation 5x May-June = 107.5 #N_{act}/A from CAN-17

Subtask 1.2.2 McCormack orchard begin seasonal tissue analyses and evaluation of N partitioning (Table 10, 2010-2012)**.**

<u>2010</u>: April 2010 values for tissue N levels indicated significant differences in shoot and bearing spur leaves (but not non-bearing spur leaves) which can be assumed to be baseline values different between the two orchard halves (i.e. North half vs South half) due to tree vigor, cropping and soil/water differences within the orchard. Those for 'Low N, high vigor' shoot leaves were 0.1% lower than 'High N, low vigor' shoot leaves; 'Low

N, high vigor' bearing spur leaves were 0.13% lower than 'High N, low vigor' shoot leaves. Tissue N for non-bearing spur leaves was similar to that of shoot leaves, bearing spur leaves was considerably lower than either of those leaf types. The significant differences within leaf type were probably due to the following factors:

- 'High N, Low vigor' trees were much smaller with lower vigor, less crop, so 'loss' of N to cropping and vegetative growth may be less.
- Heavier cropping tends to dilute mineral content found in leaves; 'high vigor' trees were much more heavily cropped in this orchard.

In July 2010, once differential N treatments were begun, significant differences were found in shoot leaves; tissue N had decreased ~0.25% from April. No differences in tissue N was found in bearing spur leaves; tissue N had dropped ~0.6% from April values, to ~2.1% for each N treatment. Although these were statistically significant differences due to treatment, the differences were very small, despite the great differential in N level. October 2010 leaf values did not differ by treatment.

2011: Highly significant differences for tissue N were found in all types of leaves in Spring, 2011; N levels were not greatly different for either shoot or non-bearing spur leaves from Spring, 2010 levels (before differential treatments were begun), but were noticeably lower for bearing spur leaves.(approximately 0.2% for each treatment, from the respective 2010 Spring level).
and in July, prior to harvest. The difference in tissue N for non-bearing spur leaves was much less between N treatments in July than in April. Bearing spur leaves showed significantly different tissue N levels in April and September of 2011, but not in either 2010 or in July 2011. Only bearing spur leaves for sample times when tissue N was different by treatment showed <u>lower</u> N for <u>higher</u> N application (September 2011). All leaf types showed depleted N levels from Spring to mid-Summer, as the developing crop and growing tree removed N for growth, as well as mobilization of N from leaves to reserve tissues at the beginning of Fall.
When Mixed Linear Regression analysis was applied to 2011 tissue N data for **McCormack,** the results of significant effects were almost identical to those of **Elliot I**, in that 'replicate' effects were highly significant for April and July tissue analyses, but also for September, in the case of **McCormack**. Nitrogen treatment level was also highly significant for April and July, less so for September. Leaf type sampled was highly significant for all collection timings. No N treatment x replicate interactions were significant for any timing. The similarity between results in two quite different trials allows greater confidence in the results in both cases as a function of differential N treatment. N partitioning, spatially by leaf type, and throughout the growing season were clear. A future study to clarify best sampling practices for tissue N could build on this information, as could a study on 'demand' timing of N application. **2012:** No differences in tissue N due to differential N application were found among leaf types within any collection date. As no replicate differences were found either, we must assume that tissue N testing for N treatment differences was not meaningful in this study after 3 years of at least double the N applied to half the orchard, and despite the much smaller overall size of the trees in that half.

Table 10. **McCormack**, 2010-2012 tissue N (% nitrogen). Comparison of North half of orchard ('High N, low vigor') and South half of orchard ('Low N, high vigor') within leaf type for treatment effects. Differential N treatment begun with May-June fertigation, 2010.

Date of sampling	'Treatment' and tree type by vigor	Shoot leaf	Spur leaf	
			Non-bearing	Bearing
2010: 282 #N_{act}/A/yr 'High N, low vigor' vs 129 #N_{act}/A/yr 'Low N, high vigor'				
April 28	High N, low vigor	3.05 a** [x]	2.93 a	2.67 a**
	Low N, high vigor	2.95 b	2.93 a	2.54 b
July 12	High N, low vigor	2.80 a*		2.06 a
	Low N, high vigor	2.72 b		2.09 a
Oct 6	High N, low vigor	2.09 a		2.10 a
	Low N, high vigor	2.15 a		2.03 a
2011: 313.5 #N_{act}/A/yr 'High N, low vigor' vs 150.5 #N_{act}/A/yr 'Low N, high vigor'				
April 29	High N, low vigor	2.99 a**	2.92 a***	2.46 a**
	Low N, high vigor	2.88 b	2.83 b	2.37 b
July 18	High N, low vigor	2.56 a	2.38 a*	2.18 a
	Low N, high vigor	2.56 a	2.28 b	2.13 a
Sept 27	High N, low vigor	2.19 a		2.07 b**
	Low N, high vigor	2.20 a		2.13 a
2012: 255 #N_{act}/A/yr 'High N, low vigor' vs 107.5 #N_{act}/A/yr 'Low N, high vigor'				
April 30	High N, low vigor	3.19 a	2.80 a	2.34 a
	Low N, high vigor	3.23 a	2.74 a	2.37 a
July 10	High N, low vigor	2.89 a	2.51 a	2.15 a
	Low N, high vigor	2.78 a	2.52 a	2.14 a

means by treatment, plant part and sample time followed by a different letter were significantly different at *P* = 0.05 by Student's t-Test; *, ** and *** = 5%, 1% and 0.1%, respectively.

Table 11. Mixed linear regression analysis; effects of differential N program for **McCormack**, 2011 (leaf N content for shoot, bearing spur and non-bearing spur leaves). September samples did not include non-bearing spur leaves. Significant effects shown as shaded.

	April	July	September
Nitrogen level	<.0001	0.006	0.02
Replicate block (consisting of 4 'tree quads')	<.0001	0.0002	0.01
Tree quad	0.018	0.56	0.15
Leaf type	<.0001	<.0001	<.0001
Nitrogen*rep	0.22	0.75	0.06
Nitrogen*leaf type	0.67	0.12	0.10

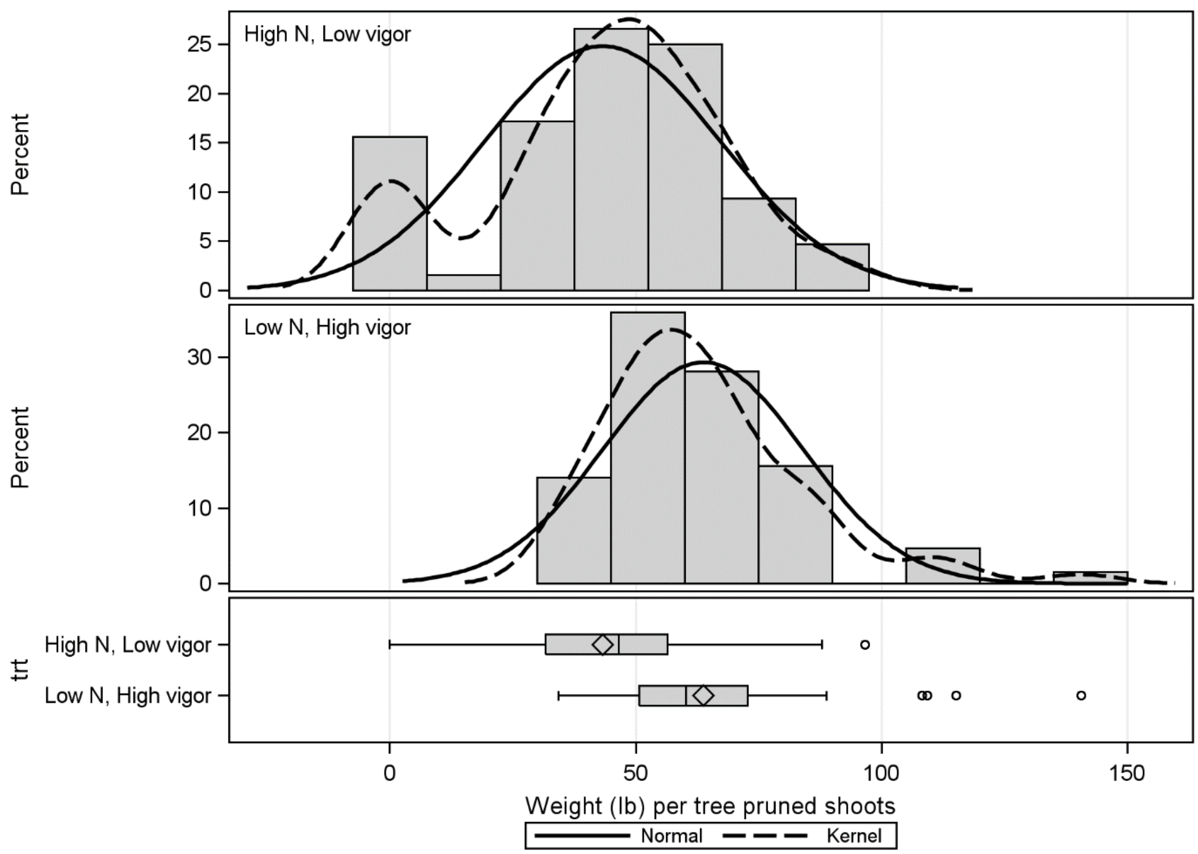


Figure 5. **McCormack orchard:** distribution of pruning weights, February 2011. Both the 'High N, low vigor' treatment and the 'Low N, high vigor' treatment show data 'spread' in the form of outliers (open circles beyond the 'whiskers' found in the graph below. While the averages for the two tree groups were quite different, this data spread decreases the ability to accurately measure treatment effects.

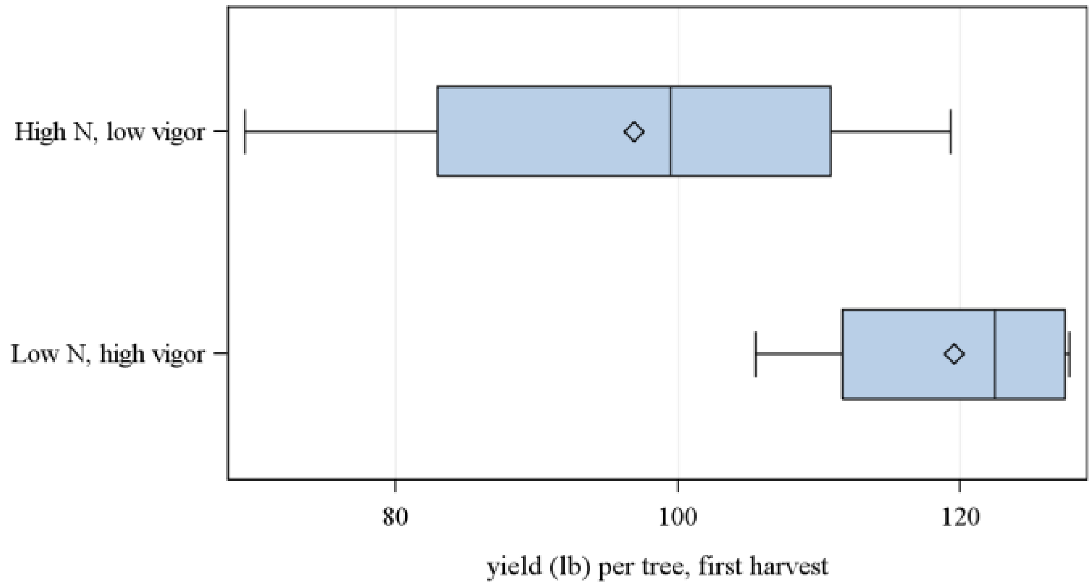
Subtask 1.2.3 McCormack orchard, assess treatment effects on vegetative and reproductive growth:

Vegetative growth, Figure 5: Vigor measured as pruning weights (Jan 28-Feb 3, 2011), was highly significant by treatment group when 'replicate' was analyzed as a random effect by the Mixed Model approach (data not shown). Not unexpectedly, the 'Low N, High vigor' trees had much higher pruning weights than did the 'High N, Low vigor' trees (63.7 vs 43.2 lb, respectively; significant at 0.1%). It was probable that this difference would persist as a function of the orchard and mature trees and was not likely to change due to N treatments.

Reproductive growth, yield and related tissue N levels:

2010, Table 12: Yields were significantly lower for the 'High N, low vigor' treatment, both in the first harvest (a 'size' pick in which all fruit were #1 fruit) and in the total for both harvests. This was an anticipated result, due to the nature of the two halves of the orchard and was the main reason for the grower's differential N treatments. The yield, overall, may not be representative of the grower's commercial yield as our 'adjustment' for tree size and bearing capacity was an experimental tool. This 'tool' for interpreting data was useful in order to reduce the variability of tree number and strength within and between treatments and replicates, thereby enabling better interpretation of treatment results. The relative yields of #1 fruit for the two treatments were similar to the overall yields, in that the 'High N, low vigor' treatment yielded less #1 fruit than did the 'Low N, high vigor' treatment. The percentage of the crop that were #1 fruit in the second harvest and total yield were not statistically different, although numerically, the 'Low N, high vigor' yielded a larger percentage of fruit that were large. This finding would suggest that the 'High N, low vigor', at the level of applied N, was probably at capacity, for this cropping year. If either half were over-cropped, fruit size would suffer; indeed, the average weights of #1 fruit and smaller fruit, by treatment, were not different. Similarly, if either half of the orchard were under-cropped, one might expect an increase in the yield of larger fruit.

2011, Table 13: The significant differences in yield components and fruit quality were: yields by weight for trees and by acre in the second and total harvests (both #1 fruit and all fruit; significantly greater for the 'Low N' treatment) and the size of smaller fruit (greater for 'Low N' treatment). In this year the percent yield removed in the first harvest (all fruit and #1 fruit) was not different by treatment group, furthering one of the grower's goals—that an improved percentage of the crop be picked in the first harvest on the low vigor trees. Tissue N for non-bearing spur leaves prior to this harvest was adequate for the 'High N, low vigor' trees (2.38% N) and slightly under the adequate range, but above critical value for the 'Low N, high vigor' trees (2.28% N). 2011 was the heaviest cropping year for this trial, so one would expect to see the results of that in tissue N responses. No other differences were found for shoot or bearing spur leaves prior to harvest. Bearing spur leaves, those that one would expect to be the strongest nutrient sources for growing fruit, showed a significant difference in tissue N in fall (2.07% N 'High N, low vigor' vs 2.13% N 'Low N, high vigor'). These two results might indicate further need for comparing both types of spur leaves before and after cropping in heavy crop years, with differential bearing habit, if possible, as in this orchard. The bearing spur leaves



in the heavier cropped half of the orchard may reflect the greater demand by the crop.

Figure 6. Distribution of yields (lb) at first harvest, 2011, McCormack, to illustrate the variability due to replicates. Although the averages (represented by ◊ in the boxplots) were substantially different (97 lb/tree vs 120 lb/tree), the 'spread' in the data shows overlap, with the 'whiskers' at each end of the box showing the extremes in the data for each treatment. There was much greater 'spread' in the data for the 'High N, low vigor' trees, indicating there were trees that were much lower yielding than others, relative to the treatment (half of the orchard) as a whole. The smaller spread in the 'Low N, high vigor' group indicated that the trees in this half of the orchard were more uniform, with respect to yields in the first harvest for this year.

2012, Table 14: The significant differences in yield components and fruit quality were as before, higher yields in the 'Low N, high vigor' trees. There were also no differences in % fruit harvested in the first pick and #1 fruit as percentage of the total crop. Although the trees of the two halves were of quite different vigor, these indicators suggest that the nutritional program (both the high N applications overall and the differential N) was maximizing the cropping potential of this orchard. The up and down cycles of cropping from year-to-year (Table 15) can be explained by adverse weather as well as nutritional demands of heavy crops and subsequently lighter return crops.

Conclusions: The grower's two primary goals in this orchard were (1) to increase the reproductive (and vegetative) vigor of the low vigor half of the orchard, by increased N application, (2) to advance maturity of the low vigor half of the orchard such that more fruit can be harvested at the 'first pick', in keeping with the ripening behavior of the high vigor half. The patterns seen in 2010 through 2012 have been consistent and appear to support the grower's choices. Historic yields were 20-23 ton/A/yr; a range of management strategies have increased yields to 30-32 ton/A/yr. Both halves of the orchard received a total of 152 $\#N_{act}$/A/yr until 2010; a longer record will be needed to judge the full results of this plan, however, the high percentages of #1 fruits (fairly consistent year-to-year) with good yields indicate a strong nutritional program appropriate for this situation.

Yield efficiency calculations comparing the orchard halves were not calculated as trunk circumferences would be needed for individual tree yields comparisons. As the spacing was not different, the lower vigor trees' yield efficiency was due to size/vigor.

Table 12. **McCormack** 2010 yields and fruit quality, by harvest ('First', 'Second'). First harvest was a 'size' pick; all fruit in first harvest were of diameter 2-⅝" or greater (#1 fruit). Treatments were the north half of the orchard (low vigor trees, 282 $\#N_{act}$/A/yr) and the south half of the orchard (high vigor trees, 129 $\#N_{act}$/A/yr). Yields estimated using an adjusted value for number of trees, based on canopy size and cropping of largest, heaviest bearing trees in the trial orchard.

<table>
<tr><td rowspan="2">N treatment and vigor</td><td colspan="4">Yield/tree (lb) by harvest (first harvest all #1 fruit)</td><td colspan="3">#1 Fruit/tree (lb)</td></tr>
<tr><td>First</td><td colspan="2">Second</td><td>Total</td><td colspan="2">Second harvest</td><td>Total</td></tr>
<tr><td>High N, low vigor</td><td>69 b*X</td><td colspan="2">111 a</td><td>180 b*</td><td colspan="2">87 a</td><td>156 b*</td></tr>
<tr><td>Low N, high vigor</td><td>123 a</td><td colspan="2">133 a</td><td>256 a</td><td colspan="2">107 a</td><td>230 a</td></tr>
<tr><td rowspan="2"></td><td colspan="4">Tons/A yield by harvest</td><td colspan="3">#1 Fruit (tons/A) by harvest</td></tr>
<tr><td>First</td><td colspan="2">Second</td><td>Total</td><td colspan="2">Second</td><td>Total</td></tr>
<tr><td>High N, low vigor</td><td>7.6 b**</td><td colspan="2">12.2 a</td><td>19.8 b</td><td colspan="2">9.5 a</td><td>17.1 b**</td></tr>
<tr><td>Low N, high vigor</td><td>12.5 a</td><td colspan="2">13.5 a</td><td>26.0 a***</td><td colspan="2">10.9 a</td><td>23.4 a</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">% Total yield at first harvest</td><td colspan="2">%Yield as # 1 fruit</td><td colspan="2">#1 Fruit wt (oz) by harvest</td><td colspan="2" rowspan="2">Fruit wt (oz) smaller fruit second harvest</td></tr>
<tr><td>Second harvest</td><td>Total</td><td>First</td><td>Second</td></tr>
<tr><td>High N, low vigor</td><td>38.0 a*</td><td>77.6 a</td><td>86.0 a</td><td>7.3 a</td><td>7.7 a</td><td colspan="2">5.6 a</td></tr>
<tr><td>Low N, high vigor</td><td>48.1 a</td><td>81.0 a</td><td>92.0 a</td><td>7.2 a</td><td>7.6 a</td><td colspan="2">5.6 a</td></tr>
</table>

Table 13. **McCormack 2011** yields and fruit quality, by harvest ('First', 'Second'). First harvest was a 'size' pick; all fruit in first harvest were of diameter 2-⅝" or greater (#1 fruit). Treatments were the north half of the orchard (low vigor trees, 282 $\#N_{act}$/A/yr) and the south half of the orchard (high vigor trees, 129 $\#N_{act}$/A/yr). Yields estimated using an adjusted value for number of trees, based on canopy size and cropping of largest, heaviest bearing trees in the trial orchard.

N treatment and vigor	Yield/tree (lb) by harvest			#1 Fruit yield/tree (lb) by harvest		
	First	Second	Total	First	Second	Total
High N, low vigor	97 a	166 b*	263 b**	93 a	160 b*	253 b*
Low N, high vigor	120 a	191 a	311 a	113 a	182 a	295 a
	Tons/A yield by harvest			#1 Fruit (tons/A) by harvest		
	First	Second	Total	First	Second	Total
High N, low vigor	10.6 a	18.1 b*	28.6 b**	10.1 a	17.5 b*	27.6 b**
Low N, high vigor	13.0 a	20.8 a	33.9 a	12.4 a	19.8 a	32.2 a

N treatment and vigor	% Yield		Fruit wt (oz) by size grade and harvest		
	As the first harvest	As #1 fruit	#1 Fruit First	#1 Fruit Second	Smaller fruit second harvest
High N, low vigor	36.6 a	96.3 a	7.5 a	7.5 a	2.9 b*
Low N, high vigor	38.5 a	95.1 a	7.6 a	7.5 a	3.6 a

[x]Means followed by a different letter were significantly different at $P = 0.05$ by Student's t-Test; *, ** and *** = 5%, 1% and 0.1%, respectively. Percentage data means separated based on arcsine square root transformation (actual means shown).

Table 14. **McCormack 2012** harvest yields and fruit quality. Minimum diameter of #1 fruit were 2 ⅝" at first harvest, 2 ¾" at second harvest. Treatments were the north half of the orchard (low vigor trees, 282 #N_{act}/A/yr) and the south half of the orchard (high vigor trees, 129 lb N_{act}/A/yr). Yields estimated using an adjusted value for number of trees, based on canopy size and cropping of largest, heaviest bearing trees in the trial orchard.

N treatment and vigor	Yield/tree (lb) by harvest			#1 Fruit yield/tree (lb) by harvest		
	First	Second	Total	First	Second	Total
High N, low vigor	58 b**	129 a	187 b*	55 b**	121 a	176 b*
Low N, high vigor	90 a	184 a	274 a	83 a	170 a	253 a

	Tons/A yield by harvest			#1 Fruit (tons/A) by harvest		
	First	Second	Total	First	Second	Total
High N, low vigor	6.4 b**	14.1 a	20.5 b*	6.0 b**	13.2 a	19.2 b*
Low N, high vigor	9.8 a	20.1 a	29.9 a	9.1 a	18.5 a	27.6 a

	% Yield		Fruit wt (oz) by size grade and harvest		
			#1 Fruit		Smaller fruit second harvest
	As the first harvest	As #1 fruit	First	Second	
High N, low vigor	31 a	94 a	7.3 a	7.7 a	5.6 a
Low N, high vigor	34 a	92 a	7.2 a	7.6 a	5.6 a

[x]Means followed by a different letter were significantly different at $P = 0.05$ by Student's t-Test; *, ** and *** = 5%, 1% and 0.1%, respectively. Percentage data means separated based on arcsine square root transformation (actual means shown).

Table 15. **McCormack** yields and yield distribution **2010-2012**; percentage of crop removed in first harvest. Yields estimated using an adjusted value for number of trees, based on canopy size and cropping of largest, heaviest bearing trees in the trial orchard. Prior to 2010 the entire orchard received 152 #N_{act}/A/yr.							
#N_{act}/A/yr			Tons/A yield by harvest			% Crop removed in first harvest	
			First	Second	Total		
High N, low vigor	282	2010	7.6	12.2	19.8		38
	313.5	2011	10.6	18.1	28.6		36.6
	255	2012	6.4	14.1	20.5		31
		total	24.6	44.4	68.9	avg	35
		avg	8	15	23		
Low N, high vigor	129	2010	12.5	13.5	26		48
	150.5	2011	13	20.8	33.9		38.5
	107.5	2012	9.8	20.1	29.9		34
		total	35.3	54.4	89.8	avg	40
		avg	12	18	30		

Task 3: Elliot II: Quantify effects on crop load and fruit quality due to N, K and Ca as influenced by differential K application

Subtask 3.1 Apply treatment regime

Until 2007 the typical fertilizer program was 100 #N_{act}/A/yr immediately after harvest and a fall application of potash (application of K was 'budget dependent'). In 2007 and 2008 no fertilizer was applied as a cost-saving measure. Beginning in 2009, the block was fertigated in spring with KMend (potassium thiosulfate $K_2S_20_3$), soluble potash (K_2O) at 25% and S at 17%, by weight, for a total of 84 #Kact/A/yr. Irrigation and fertigation flow rate via this system was ~0.1"/hr. In addition, 200 lb $Ca(NO_3)_2$ was broadcast twice in spring (early May, end of June; 62 #N_{act}/A/yr + 84 #Ca_{act}/A/yr) and a small amount of urea was added to fire blight sprays (final #N_{act}/A/yr from urea 0.7-2.76 #N_{act}/A/yr) for 'fruit finish'. Therefore, the entire trial area had received a Spring Fertigation K treatment in 2009 and no Soil K treatment in Fall, 2009. Differential K treatment began May-June 2010.

- **'Fertigation' treatment:** Spring K Fertigation in 2009-2012 as KMend ($K_2S_20_3$) =28 #K_{act} in three equal applications, May-June (84 #K_{act}/A/yr total), timing varied with weather conditions
- **'Soil' treatment:** Spring K Fertigation in 2009 + Soil K in 2010 and 2011 as a broadcast application of potash (90 #Kact/A/yr) in November

- Total $\#N_{act}$/A/yr for the trial period was ~63-65
- Total $\#Ca_{act}$/A/yr for the trial period was 47
- Total $\#K_{act}$/A/yr for the trial period was 84 or 90, respectively fertigation and soil treatments

Each treatment had four replicate 'tree quads' from which combined tissue samples were tested. Each tree, however, was individually tested for fruit quality and yield of 2-4 scaffold limbs that represented ¼ - ⅓ of the crop load.

Subtask 3.2 Tissue macro- and micronutrient concentration in leaves and small fruit:

April 2010 analyses, Table 16: *Nutrient differences within a given tissue (leaf type or fruit) by 'location' (in 'Fertigation' plot or 'Soil' plot)*

- N content was adequate (by mid-summer standards) after 0N in 2007-2008 and 63-65 $\#N_{act}$/A/yr in 2009.
- Notable differences by 'location' within a plant tissue type in this early sample were:
    - Shoot leaves – higher levels in Fertigation plot for B, Cu
    - Bearing spur leaves – higher levels in Fertigation plot for K, (K+Mg)/Ca, K/Ca and N/Ca; higher level in Soil plot for Mg
    - Non-bearing spur leaves –higher levels in Fertigation plot for Cu, Mn
- While other differences in specific nutrients and tissues were significant, none were as great statistically. In each case where a nutrient level was significantly different by 'location', the higher value was found in the 'Fertigation' plot.
- The reason for higher tissue nutrient levels in the 'Fertigation' plot trees may be that those trees were closer to the 'Scribner clay-loam', which is described as 'Surface layer …strong brown clay loam about 12" thick. The next layer is gray clay loam about 27" thick. The underlying material to a depth of 60" is stratified gray clay loam and light brownish gray sandy clay loam. In some areas the surface layer is silt loam.'
- The soil type where the entire trial was, 'Egbert clay' is described as 'Surface layer…clay about 18" thick. Below this is a buried surface layer of gray clay loam about 28" thick. The underlying material to a depth of 60" is grayish brown clay loam and sandy clay loam. In some areas the surface layer is silty clay. In other areas the dark surface layer is 14-24" thick. Permeability is slow. Available water capacity is high.'

Conclusions: Location effects (probably the soil type difference with inherent permeability and uptake effects on the rootstock) were important for a particular nutrient or balance of nutrients

April 2010 analyses, Table 17: *Detecting nutrient differences between 'locations' among all tissue types (e.g. due to changes in soil, drainage, microclimate due to slope, and the potential interactions by rootstock)*

In Table 16 we show 'location' effects within a given tissue by nutrient. We found that within some tissues, location effects were important for a particular nutrient or balance of nutrients. What other questions can we ask about this information? Table 17 summarizes the differences among all the tissues sampled by location alone. Nutrients that did not vary significantly by location alone among all the tissues are not shown.

Table 16. Nutrient values for 'Bartlett' pear, **Elliot II** orchard in April, 2010, prior to differential K treatment. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #Kact/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only in 2010. The 'Soil' treatment was subsequently treated with 300 #K_2O=150 #K_{act}/A starting in November 2010. Shaded values are different by location within the trial area as differential treatment had not occurred by sample date. Differences were likely due to soil texture and water penetration.

K treatment by fertigation or soil		% Dry weight					ppm		
		N	P	K	Ca	Mg	B	Zn	Cu
Differences within plant part (shoot or bearing or non-bearing spur leaves, or fruit) [x]									
Shoot	Fertig	3.14	0.26	1.46	0.76	0.3	34a*	31	20a*
	Soil	3.17	0.24	1.39	0.86	0.32	28b	30	17b
Bearing	Fertig	2.74	0.19	1.59a*	1.16	0.39b*	22	35	16
	Soil	2.79	0.19	1.42b	1.24	0.44a	20	34	14
Non-bearing	Fertig	3.07	0.24	1.37	0.86	0.32	26	33	17a*
	Soil	3.02	0.24	1.33	0.85	0.33	26	32	15b
Fruit	Fertig	2.50	0.29	1.65	0.19	0.19	36	28	14
	Soil	2.56	0.29	1.64	0.20	0.21	35	28	13
		S	Mn	Fe	N/K	(K+Mg)/Ca	K/Ca	Mg/Ca	N/Ca
Shoot	Fertig	1616	46	44	2.15	2.34	1.95	0.39	4.19
	Soil	1602	46	48	2.3	1.99	1.63	0.37	3.69
Bearing	Fertig	1600	135	52	1.73	1.71a***	1.37a***	0.34	2.37a*
	Soil	1598	118	51	1.98	1.50b	1.14b	0.35	2.26b
Non-bearing	Fertig	1615	57a*	47	2.24	1.98	1.6	0.38	3.58
	Soil	1602	45b	47	2.28	1.95	1.56	0.39	3.55

If we are interested in which tissues would be best to show location differences (e.g. changes in soil, drainage, microclimate due to slope, and the potential interactions by rootstock; Table 17), we can ask 'Which tissue, for each location, showed the greatest difference in nutrient levels (i.e the highest and lowest values, across all nutrients)?' Since we are trying to generalize this information to suit as many combinations of rootstock and soil/water as possible (two very important factors in how different Bartlett orchards will grow, produce and be susceptible to diseases and disorders), choosing a tissue that can best show nutrient changes in the tree for these factors is important to our search for the 'best' tissue to analyze for BMP.

While there is a high amount of overlap in statistical significance among plant parts within a given nutrient and both locations, we can count how many extremes are found for each tissue by location and how many of those extremes, by nutrient, are important in fruit quality where location difference is seen, since this is the best indicator of the rootstock x soil/water interaction.

Table **17.** Effect of 'location' on nutrient levels among plant tissues 'Bartlett' pear, **Elliot II** orchard in **April, 2010**. Only nutrients that were significantly different by location are shown.

		P	K	Mg	S	B	Zn	Fe	Cu	Mg/Ca
Fertig	Shoot	ab	ab	b	ab	ab	bc	ab	ab	a
	Bearing	ab	ab	b	abc	ab	abc	ab	ab	b
	Non-bearing	a	ab	b	ab	a	ab	ab	a	a
	Fruit	a	ab	ab	c	ab	cd	b	ab	ab
Soil	Shoot	a	ab	a	bc	ab	bc	ab	ab	ab
	Bearing	b	b	ab	abc	ab	d	ab	b	ab
	Non-bearing	ab	ab	ab	abc	ab	bcd	ab	ab	ab
	Fruit	a	a	ab	a	b	a	a	ab	ab
Significance (Tukey's, *, *** = 5%, 0.1%)		***	*	***	***	*	***	*	***	*

Number of nutrient extremes by location for each sampled tissue

	Fertigation plot	Soil plot	Total
Shoot leaf	2	2	4
Bearing spur leaf	2	4	6
Non-bearing spur leaf	5	0	5
Fruit	3	6	9

Conclusions:

- The best tissue to sample in early spring to indicate potential 'location' differences (e.g. changes in soil, drainage, microclimate due to slope, and the potential interactions by rootstock), in this case, was small fruit just after small fruit drop.

- Fruit had the highest number of nutrient extremes for both locations combined, and several extremes for each location.

April 2010 nutrient correlations, Table 18: Several correlations were found between nutrients in the tissues tested in April 2010. Most correlations were weak, with more positive than negative. Possibly the most important correlations to pay attention to were those that involve fruit quality indicators, since vigor in these trees was adequate, cropping was regular and satisfactory, fruit quality could be the factor most changed by the current fertilizer strategy, and because fruit quality postharvest showed some problems inherent to the conditions at the start of the trial.

Among nutrients known to affect fruit quality, moderate correlations include:

- Negative: Mg—K/Ca in bearing and non-bearing shoot leaves (where Mg was higher in these leaves, K/Ca ratio was lower)
- Positive:
  - P-- K+Mg/Ca, K/Ca, N/Ca in shoot leaves (where P was higher in shoot leaves, these ratios were also higher)
  - P—N in fruit (where P was higher in fruit, N was lower; high N causes 'greening' in fruit and retards maturity)

Conclusions:

- Some correlations with nutrients and their interactions that may affect fruit quality, particularly postharvest, including maturation rate and ability to store and ripen without disorders, were found in early spring sampling of tissues.
- No single tissue type was clearly the best early tissue to sample for these nutrient issues. However, the greatest number of significant correlations that were moderate were found in shoot leaves; these may be the best indicators of potential fruit disorders in this case, however, further studies would provide greater confidence of this question.

Table 18. Correlations between individual nutrients and nutrient ratios from 'Bartlett' pear tissues, **Elliot II, April 2010**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot and no applied K prior to sampling.					
	Negative			Positive	
	Strong[x]	Moderate	Weak	Moderate	Weak
Shoot	Ca-Cu		P-Ca S-N/K Mg-K/Ca	P -- K/Ca, N/Ca, (K+Mg)/Ca	P-B, K-Zn B-N/Ca
Bearing		Mg-K/Ca Fe-Mn	Mg-N/Ca		Ca-Mg
Non-bearing		Mg-K/Ca	N-B	Cu-Mn	N-Fe K-Fe S-Zn Mg/Ca-N/K
Fruit			Mg-K/Ca	P-N, Zn-Mn, Zn-Fe, S-Fe	P-Mg, P-Mn Zn-Mn, Zn-Fe

[x] 'Strong', 'moderate' and 'weak' indicate significance at 0.1%, 1% and 5%, respectively.

July 2010 analyses, Table 19:

Adequacy in nutrient levels:

- Shoot leaves, both treatments: K was slightly low
- Shoot leaves Fertigation treatment: Ca, Mn low
- Shoot leaves Soil treatment: N, P low
- However, no deficiency symptoms were observed, and trees had good vigor.

Differences between K treatments within leaf type:

- Shoot leaves and bearing spur leaves – higher levels in Fertigation plot for: N, P, S, Cu, and all the nutrient ratios but N/K.
- Shoot leaves and bearing spur leaves – higher levels in 'Soil' plot for: Ca, Mg, Mn, Zn.
- Bearing spur leaves also higher in 'Soil' plot for Fe.

The significance in each case was almost always the same for shoot and bearing spur leaves. These data indicate that either of these leaf types would have been equally valuable in detecting these K treatment differences, despite the fact that shoot leaves are part of a vegetative unit and bearing spur leaves are subtended by fruit. **The consistency in these results is very important**.

How do these values compare to the differences seen in the April samples?

- Shoot leaves – higher levels in Fertigation plot for Cu in both April and July

- Bearing spur leaves – higher levels in Fertigation plot for K, (K+Mg)/Ca, K/Ca and N/Ca at both timings.
- Bearing spur leaves -- higher level in Soil plot for Mg at both timings

Thus, the consistency across these tissue types in July and across sample timings for nutrients in bearing spur leaves that are important nutrient ratios in fruit quality are important findings.

Table 19. **July 2010** nutrient values for 'Bartlett' pear, **Elliot II** orchard. Potassium was applied by fertigation ($K_2S_20_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only in 2010. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A starting in November 2010. Possible deficient levels are shaded (deficiencies for bearing spur leaves have not been defined).

K by fertigation or soil		% Dry weight					ppm		
		N	P	K	Ca	Mg	B	Zn	Cu
Differences within plant part (shoot or spur leaves) by treatment ^{W}									
Shoot	Fertig	2.7a***	0.1a***	0.95	1.0b***	0.38b*	25	26	10.6a*
	Soil	2.1b	0.1b	0.99	1.6a	0.47a	25	32	9.4b
Bearing	Fertig	2.6a***	0.2a***	1.10	1.0b***	0.43b*	27	23.6b***	10.1a*
	Soil	2.1b	0.1b	1.09	1.6a	0.50a	25	27.5a	9.4b
Adequacy in mid-summer by leaf type (non-bearing spur ^{X} or mid-shoot ^{Y})									
Shoot		2.3-2.7	0.1-0.2	1.2-2.0	1.5-2.1	0.3-0.5	20-40	20-50	9-20
Non-bearing		2.3-2.8	0.1 -0.3	>1.0	>1.0	>1.0	21 -70	>18	>4

		ppm							
		S	Mn	Fe	N/K	(K+Mg)/Ca	K/Ca	Mg/Ca	N/Ca
Shoot	Fertig	1563a***	55b***	74b*	2.9a*	1.3a***	1.0a***	0.4a***	2.6a***
	Soil	1352b	93a	94a	2.3b	1.0b	0.7b	0.3b	1.3b
Bearing	Fertig	1628a***	35b***	90	3.1	1.4a***	1.0a***	0.4a*	2.7a***
	Soil	1338b	76a	107	2.5	1.0b	0.7b	0.3b	1.3b

Adequacy in mid-summer by leaf type (non-bearing spur or mid-shoot)

	S	Mn	Fe		
Non-bearing	>2500	>20			
Shoot	1700-2600	60-120	60-200	K/Ca that induces moderate to high chlorosis^Z	0.98-1.2

Table 20. **Elliot II, 2010**. Harvests July 26 and August 2. First harvest was a 'size' pick of all fruit ≥ 2 ⅝" diameter. Postharvest evaluations (fruit harvested July 20), 6 days ripening without storage, 3 months CA storage and 3 months CA storage + ripening 4 days. K was applied by fertigation (K2S203 (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

By harvest (1, 2, 1+2)	#1 fruit weight (oz) by harvest		Count per lb		%Crop at first harvest	#1 Fruit as % of all fruit by harvest		
	1	2	1	2		1	2	1+2
Fertigation	5.8a[x]	6.3a	2.8a	2.5a	41.6a	53.6a	61.5a	76.2a
Soil	6.0a	6.5a	2.7a	2.5a	44.9a	60.7a	65.4a	78.8a

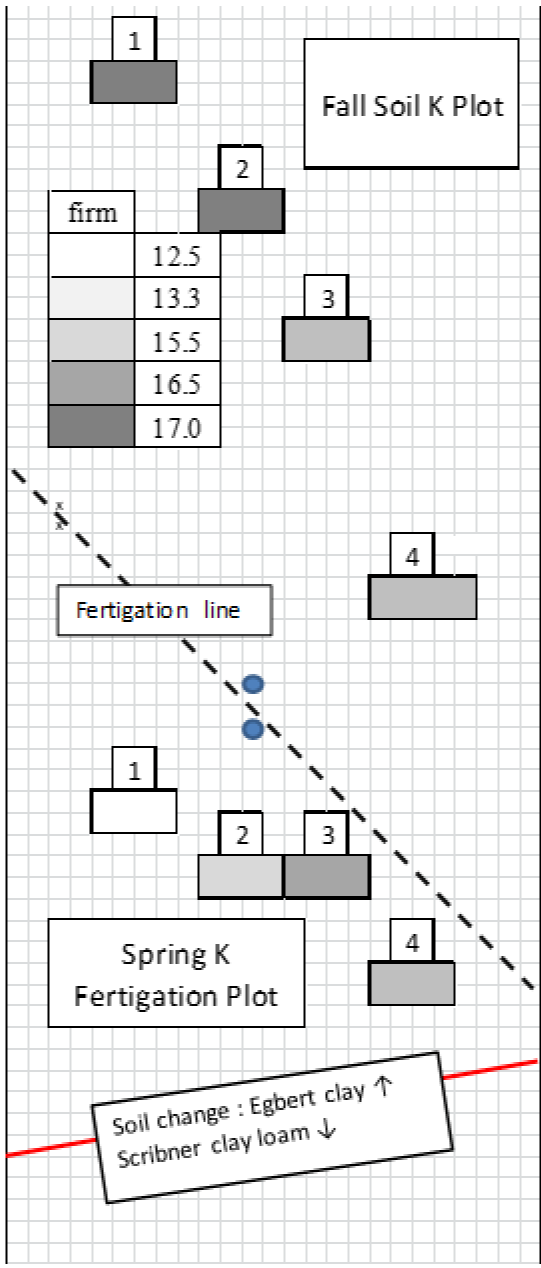
Yields per tree (combined limbs)

By harvest (1, 2, 1+2)	Total lb harvested			Total #fruit harvested			Total #1 fruit		
	1	2	1+2	1	2	1+2	1	2	1+2
Fertigation	50.1a*	79.7a*	129.8a	42.3	74.7	117.0	42.3	43.8	86.1
Soil	45.8b	61.0b	106.7b	47.9	62.6	110.5	47.9	38.2	86.1

Evaluation timing	K fertilizer	Firmness (lb)	Fruit wt (oz)	%Soluble solids	Titratable acidity	Starch	Ground or overall color
Harvest	Fertigation	17.9[x]	7.11	12.2	0.33	0.18	1.0
	Soil	17.7	7.31	12.0	0.33	0.10	1.0
Harvest+6 days	Fertigation	2.5a***		13.9	0.34b***	0.00	2.7b***
	Soil	2.3b		13.7	0.37a	0.00	3.0a
Harvest+3 mo	Fertigation	14.0b***		13.3a*	0.19		2.4a*
	Soil	15.9a		12.8b	0.20		1.9b
Harvest+3 mo +4 days	Fertigation	2.6a***		13.4	0.22		3.9a***
	Soil	2.3b		13.4	0.22		3.8b

Postharvest disorders at 6 days postharvest without storage

	Ground or overall color	Decay score	Internal browning score	Superficial scald		Senescent scald	
				Score	%Surface affected	Score	%Surface affected
Fertigation	3.91a***	0.03a	0 .70a***	0.07a	0.77a	.1a***	2.0a***
Soil	3.77b	0.06a	0.11b	0.04a	0.52a	0.0b	0.0b



x Means separation by Student's t-Test, $P = 0.05$; different letter denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively. Percentage data means separated based on arcsine square root transformation (actual means shown).

Figure 7. **Elliot II** Trial map. K treatment layout indicated with four 'replicate tree quads' numbered 1-4 per treatment. Average firmness at 3 months storage, prior to ripening, indicated by color gradient for each replicate to illustrate distribution of fruit firmness within the trial for 2010 fruit postharvest distribution. The fertigation pipe location is indicated by the dashed line and the approximate transition of soil types is indicated by solid line.

Subtask 3.32 Assess treatment effects on reproductive growth and fruit quality at harvest: We harvested 2-4 scaffolds per tree at each pick, evaluating fruit quality at harvest. All fruit harvested from subsample limbs were graded by size and weighed and counted at harvest on a fruit/limb basis. A subsample of 40 fruit per tree of the #1 fruit at the first harvest were

<u>Postharvest materials and methods (E. Mitcham and W. Biasi, UCD Plant Sciences Pomology Postharvest Lab)</u>:

On July 20th, 2010 approximately 250 fruit from each of four replications per treatment were harvested and delivered for evaluation the same day. Upon arrival the fruit were weighed and counted to determine average fruit size. Fruit were then sorted to remove damaged or blemished fruit and held overnight at room temperature. The following day, 20 fruit per replication were used for evaluation at harvest and 20 fruit per replication were ripened for 6 days at 20°C (68°F) then evaluated. Quality evaluations at harvest and after ripening included firmness, color (Minolta) and ground color (CDFA Pear Color Chart). Total soluble solids content and titratable acidity were measured on composite samples of 10 fruit each (two per replicate). Starch content was measured at harvest only.

Firmness was measured objectively using a Gűss Penetrometer fitted with an 8 mm probe. Color was measured objectively using a Minolta chromameter. Color for the group as a whole was also rated subjectively using the California Department of Food & Agriculture pear color chart (1=green; 2=light green; 3=light yellow; 4=yellow). Internal browning, decay and scald severity were scored subjectively using the following scale: 0=none; 1=slight; 2=moderate; 3=severe.
The remaining 100 fruit per replication were placed into storage at 1°C (34°F) for 3 months in room air. After storage all 100 were evaluated for presence of senescent scald and superficial scald. In addition, skin color was rated for the group as a whole using the CDFA chart. Firmness and color (Minolta) were measured on 20 fruit per replication. Total soluble solids and titratable acidity was measured on two composite samples of 10 fruit per replication. The remaining 80 fruit were transferred to 20°C (68°F) and ripened for 4 days. After ripening, additional quality evaluations were completed. All 80 were evaluated individually for senescent scald, superficial scald, percent of surface with scald, internal breakdown, decay and color (CDFA chart). Of these, 20 were used to measure firmness, color (Minolta), total soluble solids and titratable acidity.

<u>**Harvest and Postharvest, 2010**, Table 20, Figure 7</u>:

- There were no treatment differences in fruit quality at harvest timing.
- Yields per tree (combined 2-4 scaffold limbs) were greater in total weight harvested in the Fertigation plot, however, this could be due to differing numbers of limbs and volume of canopy represented by those limbs among the trees in each treatment. A better measure of overall yield differences by treatment is a comparison of

percentage gain in yield from the same limbs over the trial period (data in discussion of 2012 harvest).

- In almost every measure of storage quality in which significant differences between K treatments were found the 2010 Spring Fertigation treatment resulted in reduced quality (firmness, all evaluation timings; %soluble solids (harvest + 3 months storage; internal browning and senescent scald). Ground color and hue angle (the first is a visual measure, the second a chromameter measure of green vs yellow color, indicating ripening) was different in some evaluation timings but results by K treatment were not consistent.
- Multivariate analysis found that postharvest firmness due to K treatments ('Fertigation' plot vs 'Soil' plot) explained treatment differences at 0.1% level with April bearing spur leaf levels of Mn and Fe (1%), (K+Mg)/Ca and K/Ca (0.1%) and Mg/Ca (5%). No other regressions explain treatment differences as well.
- The 'Fertigation' plot had higher levels for (K+Mg)/Ca, K/Ca and Fe in bearing spur leaves in April and these were among those nutrient ratios associated with firmness problems in fruit from this plot.
- Significantly higher ratios (K+Mg)/Ca, K/Ca and N/Ca in the Fertigation plot indicate that the lower Ca found in both shoot and bearing spur leaves (April sampling), although not <u>statistically</u> different by K treatment plot, were functionally different with respect to the other nutrients in balances. The significantly higher K level in bearing shoot leaves, especially, would have contributed to this imbalance.
- An important predictor of these potential fruit quality problems is the N/Ca balance in the fruit. High N/Ca status (high N/low Ca) for fruit tissue is 5.3 and low N/Ca is 4.6 (Sugar et al., 1992). The N/Ca ratio found in fruit tissues sampled in April, 2010, was 12.52-13.56, indicative of exceedingly high N to low Ca balance.
- <u>Bearing spur leaf levels of these nutrients were predictive of firmness problems postharvest, as were shoot leaves and small fruit.</u>
- The July tissue analyses supported these findings. In all nutrient ratios with Ca, in both shoot and bearing spur leaves, the Fertigation plot had significantly higher ratios (i.e. lower Ca in relation to K, Mg and N) than the Soil plot.
- These results suggest that potential for storage disorders <u>was not necessarily</u> increased by the Spring 2010 Fertigation treatment (this treatment had not occurred by the April sample timing), but by the tree uptake of nutrients and their resulting balance in the tree. This was <u>likely</u> due to the proximity of these trees to the localized soil textural differences at the transition between soil types and the water permeability of that soil.
- In this case, increasing either N or K, in response to sub-optimal levels measured in leaves in April, would exacerbate the potential for fruit disorders. Indeed, applying calcium nitrate to the soil in spring did not improve the Ca tissue levels but provided increased N, which would be contraindicated.
- Because the rootstock in the sampled trees from both plots was not different, this must be a soil/water relationship for availability and uptake of these nutrients.

- Ca uptake is passive in the water stream, moving uni-directionally (mostly) to leaves in the transpiration stream, and not laterally between leaves or from leaves to other tissues. Thus, Ca sprays must contact all surfaces of the fruit to be effective.
- Leaves from Bartlett on *P. calleryana* rootstock have had higher levels of K, Mg and B than Bartlett on some other rootstocks (Lombard and Westwood, 1976; Fallahi and Larsen, 1984).
- Fallahi and Larsen (1984) also found fruit of Bartlett grown on this rootstock were high in N, P, K, Mg, Mn and Fe.
- Leaf and fruit levels of single nutrients should be obtained in spring before any fertilizer applications, examined as nutrient ratios, rather than single nutrients, and the recommended optimal leaf levels be used with caution in judging whether N, K or Mg should be applied.
- If ratios are high (Ca low in relation to N, K and/or Mg), and no other deficiency symptoms for N, K or Mg are apparent, any further application of N, K or Mg may be contraindicated.
- Uptake of Ca is often difficult and its mobility in the tree limited. There is no assurance that soil applications of Ca will be effective. Ca is needed most by the fruit in the earliest stages of fruit development. Tissue analyses as early as possible, once fully-expanded leaves and small fruit drop has occurred, shoot and bearing spur leaves, and small fruit, should be sampled for nutrients. Leaf Ca level is **not** indicative of fruit Ca level.
- Early N absorption (May to August) is negatively correlated to fruit quality (Yamazaki and Mori, 1960); there are no significant correlations with late N application (Sept to October). Nitrogen moves in the xylem like Ca and can compete with Ca for cation exchange sites, inhibiting Ca uptake and movement at a time when N is detrimental to fruit development (and enhances vigor) and when Ca is needed for fruit development. N builds up in developing fruit tissues faster than Ca does, enhancing the N/Ca imbalance that promotes fruit disorders (Shear, 1974).
- The strong recommendation of replacing the soil calcium nitrate application with foliar Ca treatments should be considered. Ca foliar applications at high frequency (up to six applications) and higher rates of Ca should be considered, as long as fruit finish is not problematic (this is, however, a possibility).
- Consider eliminating annual N application unless visual deficiency symptoms are apparent; alternatively, apply N in fall.
- When an imbalance of K/Ca or (K+Mg)/Ca is found in any leaf or fruit tissues sampled in spring, consider no K application, or consider fall soil application of K in place of K fertigation in spring so that the ratio imbalance will be less likely to affect fruit.
- Although we have focused here on the rootstock in this trial, there have been several studies done on the various rootstocks used for European pear varieties; many of these have pronounced tendencies to take up more or less of essential nutrients and

this fact can lead to fruit quality problems for many other rootstock/soil combinations. The infrequent occurrence of *P. calleryana* in California pear culture doesn't preclude similar problems in other rootstocks.

- Nor should the conclusions here be dismissed for fruit that are not going to be stored long-term (which is less common for 'summer' pears such as Bartlett). Ripening problems started showing up with the first phase of postharvest ripening (6 days after harvest).

2010 October tissue analyses, Table 21:

These samples were taken after harvest but prior to soil K treatment in the 'Soil' K plot. The main difference that one would expect would be those differences in nutrient uptake and utilization by the crop as a function of 'location'.

How did K treatment (Fertigation 2009 + 2010 vs Soil (Fertigation 2009 only by July, 2010) affect nutrient levels by leaf type and by treatment?

- Shoot leaves and bearing spur leaves – lower levels of K in Fertigation plot
- Shoot leaves – higher levels in Fertigation plot in N/K
- Shoot leaves – higher levels in Soil plot in Cu, (K+Mg)/Ca and K/Ca
- Bearing spur leaves – higher levels in Fertigation plot in Ca, Mg
- Bearing spur leaves – higher levels in Soil in B
- There do not seem to be any consistent trends from July to October.
- Although there was no difference in K in either leaf type of treatment location in July, the Fertigation plot tissues (both shoot and bearing spur leaves) were much lower in October than previously, despite the fact that this location had been fertigated with K in May-June and the Soil plot had not had K applied since Spring, 2009.
- Bearing spur leaves are much higher in Ca than shoot leaves in October; both leaf types were much higher in October than in July.
- Lower Ca in shoot leaves in October contributed to higher (K+Mg)/Ca and K/Ca

Conclusions:

- Shoot and bearing spur leaves were consistent indicators of K by 'location'
- There was little consistency between this sampling time and the April and July sampling times with respect to 'location' or tissue types
- Other than to illustrate nutrient cycling through the growing season, this sample evaluation did not provide any clear answers for the main questions to be answered in this trial.

Table 21. **October 2010** nutrient values for 'Bartlett' pear, **Elliot II** orchard. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only in 2010. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A starting in November 2010.

K treatment by fertigation or soil		% Dry weight					ppm		
		N	P	K	Ca	Mg	B	Zn	Cu
Differences within plant part (shoot or spur leaves) by treatment [X]									
Shoot	Fertig	2.04	0.13	0.69b*	1.46	0.49	28.2	26.4	7.8b*
	Soil	2.24	0.14	0.90a	1.33	0.41	28.5	30.6	8.2a
Bearing	Fertig	1.97	0.14	0.66b*	2.01a*	0.61a*	23.8b*	35.0	7.2
	Soil	2.01	0.14	0.86a	1.92b	0.54b	25.2a	40.8	8.6

		ppm							
		S	Fe	Mn	N/K	K+Mg/Ca	K/Ca	Mg/Ca	N/Ca
Shoot	Fertig	1262	154	53	3.13a*	0.79b*	0.46b***	0.34	1.40
	Soil	1375	120	64	2.51b	1.05a	0.72a	0.32	1.80
Bearing	Fertig	1298	148	56	2.90	0.65	0.34	0.30	0.98
	Soil	1300	147	74	2.34	0.73	0.45	0.28	1.05

[X] Mean separation within plant part and nutrient by Student's t test, *P* = 0.05; different letter following value denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

2011 April tissue analyses, Tables 22 and 23:

Differences by K treatment within plant part type:

- Few differences were found
- Shoot leaves in 'Fertigation' plot: higher K and Cu
- Bearing spur leaves: higher Zn in 'Soil' plot
- All were significant only at the 5% level.
- Differences among plant parts within a given K treatment were more numerous than between K treatments for a given plant part.

Conclusions:

- Fertigation and Soil K treatments appeared to have equalized the nutrient levels generally between these treatment 'locations', overcoming most differences that were likely due to soil/water changes within the orchard and the uptake responses of the rootstock to those changes.
- Shoot leaves were the best tissue to sample at this timing for K uptake differences by K treatment, although this applies only to comparing tissue types for a given nutrient by K treatment.
- **One important trend that was observed (Table 23)–bearing spur leaves in the Soil treatment showed the lowest ratios of nutrients where Ca was part of the ratio (N/Ca, (K+Mg)/Ca and K/Ca). This is of value as an indicator of potential problems for fruit quality due to low Ca. Not only is it important that this tissue was the only tissue showing this consistent relationship, the fact that the Soil K treatment improved this ratio suggests that where fruit quality problems that implicate these balances are found, postponing K application to postharvest may be of benefit.**

Differences among plant parts within a K treatment:

Fertigation plot, nutrients where significant differences were found (No differences between were found for N, Ca, Mg, Mn, Fe or any nutrient ratios):

- Fruits were among the highest accumulators of nutrients, especially in P, K, S, Zn and Cu
- Shoots were the lowest accumulators of P, K, B and Cu and the highest accumulator of N/K
- Bearing spurs tended to be lower accumulators, although not as low as shoots, while no clear pattern was seen for non-bearing spurs; non-bearing spur leaves hand the lowest N/K ratio

Soil K plot, nutrients where significant differences were found (No differences among plant parts were found for P, Ca, Zn or Mn):

- Shoots were high accumulators of N, K, Mg, Fe and Cu and low accumulators of B
- Bearing spurs were high accumulators of Mg, S, B, and N/K and low accumulators of K and Cu
- Non-bearing spurs were high accumulators of Cu and low accumulators of Mg, B and N/K
- Fruits were high accumulators of Mg and low accumulators of N, K, S, B, Fe, Cu and N/K
- Overall, leaves were poor indicators of fruit nutrient level, with shoot leaves more or less the opposite extreme for most nutrients where differences were found.

In common between K treatments:

- No differences among plant parts for Ca or Mn, but five instances of nutrients where one K treatment showed no differences but the other did show differences among plant parts for nutrient levels suggests the influence of local soil/water conditions on uptake by the rootstock influencing nutrients and their distribution in the tree.

Conclusions:

- When comparing tissue types for sampling, within a given K treatment plot, the greatest differences in nutrient level extremes were found between fruit (generally high levels of nutrients where there were significant differences) and shoot leaves (generally low levels of nutrients). Spur leaves from bearing and non-bearing spurs tended to show generally moderate levels of nutrients.
- If a single tissue type were collected, and conclusions drawn from that tissue analysis for nutrient status in the tree, misleading information would result.
- However, if only shoot leaves and fruits were collected, the conflicting information on nutrient levels would not provide the grower with useful information, without some other previously developed information, such as fruit nutrient levels and their predictability for potential quality problems.

Comparison to nutrient values in April, 2010:

- Virtually no similarities regarding differences by location (2010) or K treatment (fertigation vs soil K) by plant part nutrient level,
- The exception of nutrient ratios by 'location' (K treatment plot) **in bearing spur leaves**. These similarities were:
    - Higher N/K in Soil than Fertigation
    - Lower Soil than Fertigation for (K+Mg)/Ca, K/Ca and N/Ca

Conclusion: Together with the April 2011 finding that bearing spur leaves in the Soil treatment showed the lowest ratios of nutrients where Ca was part of the ratio (N/Ca, (K+Mg)/Ca and K/Ca), these data suggest that where fruit quality problems that implicate these balances are found, postponing K application to postharvest may be of benefit. This result was consistent both before and after differential treatment.

Important similarity between October 2010 nutrient levels and April 2011 levels:

- Shoot leaves in Soil K plot had higher levels in October 2010, before soil treatments with K and still had higher levels than the Fertigation plot in April 2011.

Conclusions:

Generally, there were more differences than similarities between treatments when comparing either April, 2010 vs 2011 or October, 2010 vs April, 2011, suggesting that the Soil K application in November, 2010 was altering the nutrient level differences from 2010 to 2011 and equalizing them with the Fertigation treatment applied in Spring, 2010, as well as potentially overcoming some of the differences due to 'location' (i.e. soil/water differences and interactions of these with the rootstock).

Table 22**.** Nutrient values for 'Bartlett' pear, **Elliot II** orchard in **April 2011**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

K treatment		% Dry weight					ppm					
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Differences within plant part (shoot or spur leaves, or fruit) by treatment												
Shoot	Fertig	2.76[x]	0.26	1.45b*	0.84	0.38	1535	26	30.2	68	57	11.7b*
	Soil	3.06	0.28	1.85a	0.86	0.36	1585	31	33.7	65	67	16.5a
Bearing	Fertig	2.72	0.26	1.76	0.76	0.32	145	35	27.1b	48	61	12.4
	Soil	2.90	0.27	1.61	0.98	0.37	166	38	36.5a	75	59	13.6
Non-bearing	Fertig	2.73	0.27	1.92	0.83	0.37	155	30	36.2	59	65	14.0
	Soil	2.77	0.27	1.84	0.83	0.30	158	29	33.8	66	61	15.4
Fruit	Fertig	2.80	0.28	1.83	0.71	0.31	163	30	37.0	78	62	15.9
	Soil	2.69	0.28	1.69	0.86	0.36	154	28	32.5	78	53	13.6
Differences among parts (shoot or spur leaves, or fruit) by treatment												
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Fertig	Shoot	a	b	b	a	a	ab	c	bc	a	a	c
	Bearing	a	b	ab	a	a	b	a	c	a	a	bc
	Non-	a	ab	a	a	a	ab	bc	ab	a	a	ab
	Fruit	a	a	a	a	a	a	b	a	a	a	a
	Significance		**	**			**	***	**			***
Soil	Shoot	a	a	a	a	a	ab	b	a	a	a	a
	Bearing	b	a	b	a	a	a	a	a	a	ab	b
	Non-	bc	a	ab	a	b	ab	b	a	a	ab	a
	Fruit	c	a	b	a	a	b	b	a	a	b	b
	Significance	***		**		***	**	***			**	***

[x] Mean separation within plant part and nutrient by LSMeans; P = 0.05; different letter following value denotes significant difference. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

Table 23. Ratios of nutrients for 'Bartlett' pear, **Elliot II** orchard in **April 2011**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.						
K treatment		N/K	(K+Mg)/Ca	K/Ca	Mg/Ca	N/Ca
Differences within plant part (shoot or spur leaves, or fruit) by treatment [X]						
Shoot	Fertigation	2.0	3.8	3.2	0.63	5.4
	Soil	1.7	3.9	3.3	0.57	5.4
Bearing	Fertigation	1.6	3.9	3.3	0.55	5.0
	Soil	1.8	3.1	2.6	0.49	4.4
Non-bearing	Fertigation	1.4	4.3	3.7	0.61	5.2
	Soil	1.5	3.7	3.2	0.46	4.7
Fruit	Fertigation	1.5	4.4	3.8	0.61	6.0
	Soil	1.6	3.8	3.2	0.57	4.9
Differences among parts (shoot or spur leaves or fruit) by treatment						
Fertigation	Shoot	a	a	a	a	a
	Bearing	ab	a	a	a	a
	Non-bearing	b	a	a	a	a
	Fruit	ab	a	a	a	a
	Significance	*				
Soil	Shoot	ab	a	a	a	a
	Bearing	a	a	a	a	b
	Non-bearing	b	a	a	a	ab
	Fruit	b	a	a	a	ab
	Significance	**				*
[X] Mean separation within plant part and nutrient by Student's t test, P = 0.05; different letter following value denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.						

2011 July tissue analyses. Table 24 and 25:

Adequacy in nutrient levels, 2010 vs 2011:

- Shoot leaves, both treatments were low in:
    - 2010 K
    - 2011 K, Ca, Mn, Cu
- 2010, Shoot leaves fertigation treatment: Ca, Mn
- 2010, Shoot leaves Soil treatment: N, P
- 2011, Non-bearing spur leaves: K, Mg, S low in both treatments

Conclusions:

- Soil K in fall may have helped to overcome mid-summer low levels of N and P found in 2010 (Soil plot).
- Shoot and non-bearing spur leaves in 2011 showed common inadequacy in only K. For Ca, Mg, Mn, S and Cu, only one or the other leaf type showed inadequate levels by standard recommendations for that leaf type.
- No deficiency symptoms were seen and trees had good vigor. Given the previous year's results, low Ca would be the only nutrient of concern.

Differences by K treatment within plant part type:

- Shoot leaves: N, P, B and Fe were different in shoot leaves
  - Fertigation > Soil for N, P, Fe
  - Soil > Fertigation for B
- Bearing spur leaves: Fertigation > Soil for Fe
- Non-bearing spur leaves: Fertigation > Soil for P, S (significant at 0.1%), Fe

Conclusions:

- No nutrient balances were different by treatment
- All leaf types analyzed showed higher Fe in the Fertigation plot than Soil plot
- Where differences existed by K treatment, the Fertigation treatment was higher than Soil for all but B
- K treatment by fertigation increased levels of N, P, Fe, S in some leaf types but not others.
- Higher N prior to harvest could be problematic for fruit, although nutrient balances were not different by treatment.

Differences among plant parts within a K treatment:

- Treatment differences across plant parts were numerous and highly significant in all nutrients we tested.
- Levels tended to be higher in 7 out of 11 single nutrients within shoot tissues and when treatment differences were tested across leaf types.
- Shoot leaves had highest levels in almost all cases.
- All ratios were different across leaf types and most highly significant.
- Same order of high to low values for plant parts when comparing the K treatments: P, B, Zn, Fe, Cu, (K+Mg)/Ca, Mg/Ca and N/Ca
- N/K and K/Ca were not greatly different among plant parts when comparing the K treatments.

- It was not possible to conclude that one leaf type was better to sample than another based on this data alone.

Table 24. Nutrient values for 'Bartlett' pear, **Elliot II** orchard in **July, 2011**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

K treatment		% Dry weight					ppm					
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Differences within leaf type (shoot or spur) by treatment [W]												
Shoot	Fertig	2.71a*	0.17a*	0.9	1.3	0.45	1855	30.2b*	28	47	94a**	3.0
	Soil	2.52b	0.15b	0.9	1.2	0.39	1608	31.6a	29	56	73b	2.8
Bearing	Fertig	2.17	0.14	1.1	1.7	0.49	1605	28.6	27	80	119a**	2.0
	Soil	2.12	0.14	1.2	1.7	0.43	1508	29.1	30	89	104b	1.8
Non-bearing	Fertig	2.47	0.15a*	0.8	1.7	0.54	1818a***	26.1	32	49	113a**	3.2
	Soil	2.36	0.14b	0.7	1.7	0.58	1605b	24.5	39	68	91b	3.4
Adequacy in mid-summer by leaf type (non-bearing spur [X] or mid-shoot [Y])												
Leaf type		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Shoot		2.3-2.7	0.1-0.2	1.2-2.0	1.5-2.1	0.3-0.5	1700-2600	20-40	20-50	60-120	60-200	9-20
Non-bearing		2.3-2.8	0.1 -0.3	>1	>1	>1	>2500	21 -70	>18	>20		>4

Differences among parts (shoot or spur leaves, or fruit) by treatment												
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Fertig	Shoot	a	a	a	c	a	a	a	b	b	b	a
	Bearing	c	b	b	a	b	b	a	b	a	a	b
	Non-bearing	b	b	b	b	c	a	b	a	b	a	a
	Significance	***	***	***	***	***	***	***	*	***	**	***
Soil	Shoot	a	a	b	b	b	a	a	b	c	b	a
	Bearing	b	b	a	a	a	a	a	b	a	a	b

Table 25. Ratios of nutrients for 'Bartlett' pear, **Elliot II** orchard in **July 2011**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

K treatment		N/K	(K+Mg)/Ca	K/Ca	Mg/Ca	N/Ca
Differences within leaf type (shoot or spur) by treatment[X]						
Shoot	Fertigation	1.10	0.74	0.36	2.17	1.95
	Soil	1.12	0.78	0.34	2.20	1.67
Bearing	Fertigation	0.92	0.65	0.28	1.24	1.59
	Soil	0.94	0.68	0.25	1.26	1.82
Non-bearing	Fertigation	0.79	0.47	0.32	1.48	1.44
	Soil	0.71	0.42	0.29	1.42	1.53
Differences among parts (shoot or spur leaves or fruit) by treatment						
Fertigation	Shoot	a	a	a	a	a
	Bearing	ab	b	b	c	c
	Non-bearing	b	c	c	b	b
	Significance	*	***	***	***	***
Soil	Shoot	ab	a	a	a	a
	Bearing	a	b	a	c	c
	Non-bearing	b	c	b	b	b
	Significance	**	***	***	***	***
K/Ca that induces moderate to high chlorosis 0.98-1.2 (Lindner and Harley, 1944)						

[X] Mean separation within plant part and nutrient by Student's t test, P = 0.05; different letter following value denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

Subtask 3.32 Assess treatment effects on reproductive growth and fruit quality at harvest: We harvested 2-4 scaffolds per tree at each pick, evaluating fruit quality at harvest.

<u>**Harvest 2011**, Table 26</u>:

Significant differences by K treatment:

- Fruit were slightly larger in general with Fertigation, although differences were very small
- A slightly higher number of #1 fruit were found in the Soil treatment <u>as a percentage of the overall harvest</u>, but the difference was small; yield of #1 fruit was higher in the Fertigation treatment in actual numbers.
- Yields tended to be higher overall for the Fertigation treatment, however, irregular numbers of limbs and actual canopy consisting of those limbs varied from tree-to-tree.

A better comparison would be a percentage of change per treatment over the trial period (see final yield calculations at end of 2012 harvest data).

Table 26. **Elliot II, 2011**: Harvests July 27 (1st) and August 10-11 (2nd). First harvest was a 'size' pick of all fruit ≥ 2 1/2" diameter and minimum size for #2 fruit at the second harvest was 2 ¼", due to an exceptionally heavy crop year. Potassium was applied by fertigation (K2S203 (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

K treatment	Fruit weight (oz)	#Fruit/lb		Fruit in 1st harvest		#1 Fruit as % of total fruit harvested 2nd	#1 fruit as % of total harvest
	1st	1st	2nd	% of total #1 fruit	% of total harvest		
Fertigation	5.8b* x	2.8a*	2.8a*	58.4	53.6	81.3	90.4b*
Soil	6.0a	2.7b	2.6b	63.8	60.7	84.8	93.7a

Yields per tree (combined limbs)

By harvest (1, 2, 1+2)	Total lb harvested			Total #fruit harvested			Total #1 fruit		
	1	2	1+2	1	2	1+2	1	2	1+2
Fertigation	33.9	27.2a*	61.1	92.5a*	75.4a*	167.9a*	92.5a*	61.1	153.6a*
Soil	32.2	22.7b	54.9	85.2b	60.9b	146.1b	85.2b	51.1	136.3b

2011 September tissue analyses, Tables 27 and 28:

Differences by K treatment within plant part type:

- Soil > Fertigation for Mn for both shoot and bearing spur leaves; no other differences were found.

Differences among plant parts within a K treatment:

- Bearing spur leaves > shoot leaves for Ca, Mg in both Fertigation and Soil treatments
- Bearing spur leaves > shoot leaves for Zn in Soil treatment and for Fe and Cu in Fertigation treatment
- Shoot leaves > bearing spur leaves for: N/K, (K+Mg)/Ca, K/Ca, in Fertigation treatment.
- Shoot leaves > bearing spur leaves for: Mg/Ca and N/Ca in both K treatments.

Conclusions:

- Within a given plant part, K treatment was not different except for Mn. Any leaf type sampled would have given similar results for treatment differences.
- However, bearing spur leaves and shoot leaves showed significant differences in how much of given nutrients they accumulated; these differences occurred often in both treatments.
- In most cases where nutrient level differed by leaf type, bearing spur leaves had higher levels than shoot leaves.
- Because bearing spur leaves accumulated higher levels of Ca than did shoot leaves, ratios with Ca were lower for spur leaves than shoot leaves, across both K treatments.
- It is possible that higher accumulation of Ca by bearing spur leaves may indicate higher accumulation of Ca by subtending fruit, but that is not conclusive without sampling fruit tissues. Ca is not mobile in the plant, except with the transpiration stream, thus preferential accumulation by leaves over fruit is assumed (although fruit must accumulate water for enlargement, this may be due more to osmotic pressure differences than transpiration pull).
- When comparing to July differences, results were different as shoot leaves had highest levels in almost all cases where there were differences among leaf types.
- July values were not good predictors of September values; this was also the case in 2010.

Table 27. Nutrient values for 'Bartlett' pear, **Elliot II** orchard in **September 2011**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

K treatment by fertigation or soil		% Dry weight					ppm					
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Differences within plant part (shoot or spur leaves, or fruit) by treatment[x]												
Shoot	Fertig	2.16	0.15	0.79	1.54	0.45	1522	23.6	30.3	57b*	148	7.93
	Soil	2.18	0.15	0.77	1.52	0.43	1462	23.4	33.6	76a	153	8.33
Bearing	Fertig	2.03	0.14	0.81	1.98	0.53	1532	23.7	35.0	59b*	170	8.93
	Soil	2.02	0.15	0.87	2.00	0.50	1522	24.3	40.3	83a	166	9.70
Differences among parts (shoot or spur leaves, or fruit) by treatment												
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Fertig	Shoot	a	a	a	b	b	a	a	a	a	b	b
	Bearing	a	a	a	a	a	a	a	a	a	a	a
	Significance				**	***					**	*
Soil	Shoot	a	a	a	b	b	a	a	b	a	a	a
	Bearing	b	a	a	a	a	a	a	a	a	a	a
	Significance	**			**	*			*			

[x] Mean separation within plant part and nutrient by Student's t test, *P* = 0.05; different letter following value denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

Table 28. Ratios of nutrients for 'Bartlett' pear, **Elliot II** orchard in **September 2011**. Potassium was applied by fertigation ($K_2S_20_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

K treatment by fertigation or soil		N/K	(K+Mg)/Ca	K/Ca	Mg/Ca	N/Ca
Differences within plant part (shoot or spur leaves) by treatment[X]						
Shoot	Fertig	2.78	0.81	0.51	0.29	1.40
	Soil	2.86	0.79	0.51	0.28	1.44
Bearing	Fertig	2.52	0.68	0.41	0.27	1.03
	Soil	2.36	0.69	0.44	0.25	1.02
Differences among parts (shoot or spur leaves or fruit) by treatment						
Fertig	Shoot	a	a	a	a	a
	Bearing	b	b	b	b	b
	Significance	**	**	**	**	***
Soil	Shoot	a	a	a	a	a
	Bearing	a	a	a	b	b
	Significance				**	*

[X] Mean separation within plant part and nutrient by Student's t test, $P = 0.05$; different letter denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

2012 April tissue analyses. Tables 29-31:

Differences between 2011 and 2012 results

Fruit: Ca, Fe and Mn were extremely low and Mg much lower in fruit than in April 2011

Differences by K treatment within plant part type:

- Nutrient values for April 2012 were not different by treatment, for a given plant part. Therefore, data analyses were repeated with treatments combined and 'replicate' term now a combination of the 'treatment' location and original 'replicate' (now a total of 16 'replicates', instead of 8 replicates x 2 treatments).
- Shoot leaves highest in N, P, S, B, Cu, N/K
- Bearing spur leaves highest in K, Ca, Mg, Zn, Mn, Fe

- Non-bearing spur leaves highest in Ca, Mg, N/K
- Fruit highest in P, (K+Mg)/Ca, K/Ca, Mg/Ca, N/Ca and lowest in N, Ca, Mg, S, Zn, Mn, Fe
- The fact that there were no treatment differences may be due to light cropping in the 2012 year, with lower than usual nutrient demand at this time shortly after small fruit drop.
- It was not possible to conclude that one leaf type was better to sample than another based on this data alone.

July, 2012 tissue analyses, Tables 32-34:

Differences among plant parts, comparison to April, 2012 values and adequacy levels:

- Nutrient values different by treatment were found for shoot leaves (Fe) and bearing spur leaves (Mn) only (Tables 32, 33). Therefore, treatments were combined for data analyses, as for April data (Table 34). All nutrients were different among plant parts and highly significant, except for Cu.
- Shoot leaves highest in N, P, S and N/K. Both April and July high values, therefore were in N, P, S and N/K.
- Bearing spur leaves highest in K, B, Zn, Mn, Fe and (K+Mg)/Ca. Both April and July high values, therefore, were in K, Zn, Mn and Fe. Perhaps more importantly, bearing spur leaves were lowest in N, P, Mg and N/K. Maturing fruit may have been preferentially pulling these nutrients from adjacent bearing spur leaves.
- Non-bearing spur leaves were highest in Ca, Mg, S. Both April and July high values, therefore, were in Ca and Mg. The fact that growing fruit (April) were lowest in Ca, Mg and S and that the non-bearing spur leaves are highest in these same nutrients at the 'standard' sampling time for deficiencies may indicate that non-bearing spur leaves are not the best indicators for nutrient status in fruit quality considerations.
- Inadequacy based on published values (van den Ende and Leece, 1975) for mid-summer non-bearing spur leaves were found in K (non-bearing spur and shoot leaves), N (bearing spur leaves) and Ca (bearing spur and shoot leaves). Of these the lowest was Ca in shoot leaves, which may be a matter of concern when young fruit are also low, as in 2013.
- Both shoot and non-bearing spur leaves were in the range of K/Ca that indicates moderate to high chlorosis (Lindner and Harley, 1944), due to low K status in these leaves.
- Leaf nutrient values were not expressed in harvest fruit quality however low K and Ca in leaves in July and low Ca in fruit in April may have been indicators of potential postharvest disorders. This would be a good research area to pursue.

Table 29. Nutrient values for 'Bartlett' pear, **Elliot II** orchard in **April 2012**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

K treatment		% Dry weight					ppm					
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Differences within plant part (shoot or spur leaves, or fruit) by treatment[x]												
Shoot	Fertigation	3.1	0.28	1.49	170	44.2	0.56	0.28	30.0	26.3	52.2	17.2
	Soil	3.1	0.29	1.58	166	40.6	0.57	0.28	32.4	33.0	57.2	17.3
Bearing	Fertigation	2.5	0.19	1.94	155	27.2	1.07	0.37	44.4	167.	71.7	13.4
	Soil	2.3	0.19	2.16	151	27.1	1.04	0.36	49.1	181.	76.1	13.3
Non-bearing	Fertigation	3.0	0.24	1.42	162	28.4	0.99	0.38	35.0	47.5	67.6	13.2
	Soil	2.9	0.25	1.53	160	28.2	0.97	0.36	38.2	51.2	65.2	13.6
Fruit	Fertigation	2.5	0.29	1.85	116	40.0	0.16	0.18	29.2	18.5	26.8	13.6
	Soil	2.4	0.30	1.83	116	36.2	0.19	0.19	28.8	19.9	29.6	13.0
Differences among parts (shoot or spur leaves, or fruit) by treatment												
Fertig	Shoot	a	ab	c	a	a	c	b	bc	bc	c	a
	Bearing	c	d	a	b	c	a	a	a	a	a	b
	Non-	b	c	cd	b	c	ab	a	b	b	ab	b
	Fruit	c	a	ab	c	b	d	c	c	cd	d	b
	Significance	***	***	***	***	***	***	***	***	***	***	***
Soil	Shoot	a	a	c	a	a	b	b	b	bc	c	a
	Bearing	b	c	a	b	c	a	a	a	a	a	b
	Non-	a	b	c	b	c	ab	a	ab	b	bc	b
	Fruit	b	a	b	c	b	c	b	c	c	d	b
	Significance	***	***	***	***	***	***	***	***	***	***	***

[x] Mean separation within plant part and nutrient by LSMeans; P = 0.05; different letter following value denotes significant difference. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

Table 30. Ratios of nutrients for 'Bartlett' pear, **Elliot II** orchard in **April 2012**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 $\#K_{act}$/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 $\#K_{act}$/A in November 2010-2011.

K treatment by fertigation or soil		N/K	(K+Mg)/Ca	K/Ca	Mg/Ca	N/Ca
Differences within plant part (shoot or spur leaves, or fruit) by treatment[x]						
Shoot	Fertig	2.10	3.00	2.68	0.51	5.56
	Soil	1.98	3.50	2.83	0.49	5.50
Bearing	Fertig	1.30	2.00	1.80	0.35	2.34
	Soil	1.08	2.50	2.10	0.35	2.25
Non-bearing	Fertig	2.10	2.00	1.45	0.38	3.01
	Soil	1.90	2.00	1.55	0.37	2.99
Fruit	Fertig	1.35	12.50	11.25	1.13	15.29
	Soil	1.32	11.25	9.95	1.04	13.25
Differences among parts (shoot or spur leaves or fruit) by treatment						
Fertig	Shoot	a	b	b	b	b
	Bearing	b	bc	c	c	c
	Non-bearing	a	c	c	c	c
	Fruit	b	a	a	a	a
	Significance	***	***	***	***	***
Soil	Shoot	a	b	b	b	b
	Bearing	d	ab	bc	c	d
	Non-bearing	ab	bc	c	c	c
	Fruit	c	a	a	a	a
	Significance	***	***	***	***	***

[x] Mean separation within plant part and nutrient by Student's t test, $P = 0.05$; different letter following value denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

Table 31. Combined nutrient values for 'Bartlett' pear, **Elliot II** orchard in **April 2012**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertigation' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011. No differences were found between treatments and within types of plant parts, therefore values for the separate K treatments were combined.

	% Dry weight					ppm		
	N	P	K	Ca	Mg	S	B	Zn
Shoot	3.1a***	0.29a***	1.5c***	0.56b***	0.28b***	1685a***	42a***	31c***
Bearing	2.4c	0.19c	2.1a	1.06a	0.36a	1531c	27c	47a
Nonbearing	2.9b	0.24b	1.5c	0.98a	0.37a	1610b	28c	37b
Fruit	2.4c	0.30a	1.8b	0.18c	0.19c	1165d	38b	29c

	ppm							
	Mn	Fe	Cu	N/K	K+Mg/Ca	K/Ca	Mg/Ca	N/Ca
Shoot	30c***	54c***	17a***	2.04a***	3.2b***	2.8b***	0.5b***	5.5b***
Bearing	175a	74a	13b	1.19c	2.2c	2.0c	0.4c	2.3c
Nonbearing	49b	66b	13b	2.00a	2.0c	1.5c	0.4c	3.0c
Fruit	19c	29d	13b	1.33b	11.7a	10.4a	1.1a	13.9a

[x] Mean separation within plant part and nutrient by LSMeans; P = 0.05; different letter following value denotes significant difference. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

Table 32. Nutrient values for 'Bartlett' pear, **Elliot II** orchard in **July 2012**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

		% Dry weight					ppm					
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Differences within leaf type (shoot or spur) by treatment[X]												
Shoot	Fertig	2.8	0.16	1.08	1790	29.5	1.1	0.5	26.3	43.7	104.6a*	11.0
	Soil	2.8	0.17	1.05	1758	29.1	1.2	0.5	28.1	55.8	94.1b	11.0
Bearing	Fertig	2.1	0.14	1.82	1535	33.0	1.3	0.4	38.9	153.5b*	140.9	11.3
	Soil	2.1	0.14	1.85	1485	32.1	1.3	0.3	43.9	182.2a	136.9	11.5
Non-bearing	Fertig	2.5	0.15	1.11	1710	28.6	1.6	0.5	31.7	51.7	119.8	17.0
	Soil	2.5	0.15	1.14	1685	30.4	1.6	0.5	34.4	54.2	124.5	10.3

Differences among parts (shoot or spur leaves, or fruit) by treatment												
		N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
Fertig	Shoot	a	a	b	a	b	b	a	b	b	b	a
	Bearing	c	a	a	c	a	b	a	a	a	a	a
	Non-bearing	ab	a	b	b	c	a	a	ab	b	b	a
	Significance	**		**	***	***	*		*	***	*	
Soil	Shoot	a	a	a	a	b	b	a	b	b	b	a
	Bearing	b	a	a	a	b	b	b	a	a	a	a
	Non-bearing	ab	a	a	a	a	a	a	b	b	a	a
	Significance	*				*	***	**	**	***	**	

[X] Mean separation within plant part and nutrient by Student's t test, *P* = 0.05; different letter following value denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

Table 33. Ratios of nutrients for 'Bartlett' pear, **Elliot II** orchard in **July 2012**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

		N/K	(K+Mg)/Ca	K/Ca	Mg/Ca	N/Ca
Differences within leaf type (shoot or spur) by treatment[x]						
Shoot	Fertig	2.60	1.00	0.95	0.40	2.45
	Soil	2.68	1.00	0.88	0.38	2.34
Bearing	Fertig	1.17	1.75	1.40	0.27	1.63
	Soil	1.15	1.75	1.45	0.25	1.67
Non-bearing	Fertig	2.30	1.00	0.65	0.33	1.52
	Soil	2.23	1.00	0.70	0.31	1.55
Differences among parts (shoot or spur leaves or fruit) by treatment						
Fertig	Shoot	a	b	b	a	a
	Bearing	c	a	a	c	b
	Non-bearing	b	b	c	b	b
	Significance	***	***	***	***	***
Soil	Shoot	a	b	b	a	a
	Bearing	c	a	a	c	b
	Non-bearing	b	b	b	b	c
	Significance	***	*	*	***	***

[x] Mean separation within plant part and nutrient by Student's t test, $P = 0.05$; different letter following value denotes significant difference within given nutrient and leaf type. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

Table 34. Combined nutrient values for 'Bartlett' pear, **Elliot II** orchard in **July 2012**. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertigation' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011. No differences were found between treatments and within types of plant parts, therefore values for the separate K treatments were combined for analyses.[X]

	% Dry weight					ppm		
	N	P	K	Ca	Mg	S	B	Zn
Shoot	2.8a***	0.16a***	1.1b***	1.18b***	0.46b***	1774a***	29.3b**	27.2c**
Bearing	2.1c	0.14c	1.8a	1.32b	0.34c	1510b	32.6a	41.4a
Non-bearing	2.5b	0.15b	1.1b	1.63a	0.52a	1698a	29.5b	33.1b
Adequacy in mid-summer by leaf type (non-bearing spur [Y] or mid-shoot [X])								
Shoot	2.3-2.7	0.1-0.2	1.2-2.0	1.5-2.1	0.3-0.5	1700-2600	20-40	20-50
Non-bearing	2.3-2.8	0.1 -0.3	>1	>1	>1	>2500	21 -70	>18

	ppm							
	Mn	Fe	Cu	N/K	K+Mg/Ca	K/Ca	Mg/Ca	N/Ca
Shoot	49.8b**	99.3c***	11.4	2.64a***	1.00b***	0.91b***	0.39a***	2.39a***
Bearing	167.8a	138.9a	11.8	1.16c	1.75a	1.42a	0.26b	1.65b
Non-bearing	53.0b	122.2b	14.1	2.26b	1.00b	0.68b	0.32b	1.54c
Adequacy								
Shoot	60-120	60-200	9-20	K/Ca that induces moderate to high chlorosis 0.98-1.2 (Lindner and Harley, 1944)				
Non-bearing	>20		>4					

[Z]Mean separation within plant part and nutrient by LSMeans; P = 0.05; different letter following value denotes significant difference. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively.

[Y] Beutel, Uriu and Lilleland, 1983.

[X]van den Ende and Leece, 1975.

Table 35. **Elliot II, 2012**: Harvests July 19 and July 30. First harvest was a 'size' pick of all fruit ≥ 2 ⅝" diameter and minimum size for #2 fruit at the second harvest was 2 7/16"; smaller fruit were culls. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.

	Count per limb by grade and harvest					
	#1 Fruit			#2	Cull	Total #fruit
Harvest, first, second ('1' or '2')	1	2	1+2	2	2	1+2
Fertigation	55.5a	55.5a	111.0a	15.0a	17.6a	143.6a
Soil	61.1a	54.0a	115.1a	20.1a	9.5a	144.7a

	Weight (lb) per limb by grade and harvest					
	#1 fruit wt (lb) per limb			#2	Cull	Total wt per limb
Harvest, first, second ('1' or '2')	1	2	1+2	2	2	1+2
Fertigation	24.0a	24.1a	48.1a	27.7a	20.4a	96.2a
Soil	26.4a	24.1a	50.0a	25.1a	24.7a	105.2a

	% Harvest as #1 fruit			%Crop in first harvest	#1 fruit wt (oz)	Firmness (lb)		%Soluble solids (Brix)	
Harvest, first, second ('1' or '2')	1	2	1+2		2	1	2	1	2
Fertigation	51 a	29a	80a	41.8a	7.0a	18.3 a	16.2a	11.6a	11.9a
Soil	56 a	35a	81a	46.4a	6.9a	18.5 a	16.1a	11.6a	11.6a

[x] Mean separation within column and year by Duncan's Multiple Range Test, $P = 0.05$; different letter following value denotes significant difference. *, ** and *** indicate significance at 5%, 1% and 0.1%, respectively. All percentage data were arcsine square-root transformed prior to analyses; actual means shown.

Subtask 3.32 Assess treatment effects on reproductive growth and fruit quality at harvest:

Harvest, 2012, Table 35 and **Combined yields, 2010-2012**, Table 36:

Differences by treatment in yield and fruit quality in 2012: No differences in yield or fruit quality were found in 2012.

Cumulative yield and percent change in cumulative yield 2010-2012:

- When comparing yields from 2010 + 2011, 2010 + 2011 + 2012, the Fertigation treatment had higher yields per tree (combined limbs) than the Soil treatment. However, this difference could be explained by differences in number of limbs and volume of canopy found tree-to-tree within and between treatments.
- A better measure of treatment effect on yield would be to compare the percent change in yield over time from the same limbs and trees. There was no significant difference between treatments from 2010 to 2011. Although there was no significant difference from 2010-2012 in cumulative percent increase in yield, there was a numerical difference with the Soil treatment greater than the Fertigation treatment.

<table>
<tr><td colspan="8">Table 36. 'Tree' yields for Elliot II, 2010-2012; each 'tree' yield was for a selected group of major scaffold limbs (2-4scaffolds /sample tree; same scaffolds 2010 and 2011. Each replicate=4 sample trees). The same limbs and trees were sampled annually. Potassium was applied by fertigation ($K_2S_2O_3$ (84 #K_{act}/A/yr May-June)) in Spring, 2009 to the entire plot, then to the 'Fertig' treatment only Spring 2010-2012. The 'Soil' treatment was subsequently treated with 300 #K2O=150 #K_{act}/A in November 2010-2011.</td></tr>
<tr><td colspan="8">Fruit harvested from all sampled limbs/tree combined in first or second harvest (yield per 'tree')</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Yield (lb) by harvest</td><td colspan="2">Cumulative tree yields (for harvested limbs; lb)</td><td rowspan="4">%Increase in #fruit/limb (using #fruit/limb in 2010 as base)</td></tr>
<tr><td>First</td><td>Second</td><td>Total</td><td>2010+2011</td><td>2010-2012</td></tr>
<tr><td rowspan="2">2010</td><td>Fertig</td><td>50.1a</td><td>79.7a</td><td>129.8 a*</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Soil</td><td>45.8a</td><td>61.0a</td><td>106.7 b</td></tr>
<tr><td rowspan="2">2011</td><td>Fertig</td><td>93.2 a</td><td>74.9 a*</td><td>168.1 a</td><td>297.9 a*</td><td></td><td>137.5</td></tr>
<tr><td>Soil</td><td>78.6 a</td><td>55.1 b</td><td>133.7 a</td><td>240.4 b</td><td></td><td>136.1</td></tr>
<tr><td rowspan="2">2012</td><td>Fertig</td><td>25.6 a</td><td>73.4 a</td><td>98.4 a</td><td rowspan="2"></td><td>396.3 a*</td><td>321.9</td></tr>
<tr><td>Soil</td><td>25.5 a</td><td>68.7 a</td><td>101.2 a</td><td>341.6 b</td><td>359.6</td></tr>
</table>

Conclusions:

- This orchard was adequately fertilized, despite apparent deficiencies indicated in leaf samples.
- The potential for nutrient imbalances that can affect fruit quality, especially with storage, was amplified in the area where the soil changes occurred.
- Sampling in early spring and mid-season, especially of small fruit in spring, provided good prediction of potential for fruit disorders.
- Tissue analyses should be interpreted with caution with respect to applying nutrients, (especially N and K), that can exacerbate potential for disorders. Nutrient balances should be calculated and used to assess need for fertilizers before application.
- In order to avoid potential for fruit quality disorders Fall application of K is advised and applications of Ca in Spring should be considered as a foliar application, without added N. Any N application should be considered for fall, to reduce the likelihood of nutrient imbalances for fruit quality when those are indicated by early season tissue analyses.
- No adverse effects on yields or fruit size were caused by either K treatment, therefore, the main consideration in this orchard is reduced exposure of the fruit to N and K preharvest, and consideration of foliar Ca preharvest in numerous applications using forms that are reduced risk for fruit finish.

Dissemination of project results:

Annual pear grower meetings in the Sacramento Delta and North Coast Districts 2010-2012 have been held in winter; the project progress has been presented at each of those meetings by one of the Project Leaders. These meetings are typically attended by 30-50 growers and PCA's. Periodic reports have been posted on the UC Fruit and Nut Center Website which is accessible by the general public; these reports have also been submitted to the California Pear Advisory Board for posting on their website, should they choose. A poster was prepared and presented at the 2011 American Society for Horticultural Science annual convention that covered the to-date project at Elliot II, summarizing the nutritional effects on fruit quality and postharvest disorders. The preliminary findings were presented at the CDFA FREP meeting in Fall, 2010 and the final findings will be presented at the 2012 meeting.

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Some horticultural or disease problems that are nutrient-related arise sporadically, both in time and location. Often these kinds of problems, since they are localized, don't receive sufficient attention or research funding to develop solutions. Unanticipated benefits of many research projects can include partial answers to under-researched problems. It is our hope that the information we developed here will add to the general knowledge base in such a way.

We chose orchards for these trials with a range of soils, rootstocks and nutritional management practices so that we might take advantage of both fixed constraints and flexibility to address nutrient management with potential opportunities for effects on cropping and fruit quality. In fact, we hoped that some of the nutrient-related fruit quality problems that tend to be localized might show up for the benefit of our work, if not for the growers' benefit. We may have been disappointed in that the growers managed so well that we weren't able to find serious problems! While many of our results appeared 'non-significant' with respect to treatment differences in nutrient amount, form and timing of application, there were no 'empty' outcomes as our goals, in part, were to question the existing UC recommendations' relevancy to the varied conditions under which California's pear growers make their 'real world' decisions. We hope that the information in this report will provide impetus for future work and recognition that both researchers and growers can learn from each other. Where 'treatment differences' were not significant, it was due to the astute management of the growers and their knowledge of each orchard's unique set of challenges.

2008 Sacramento Delta District Survey (Ingels, CPAB report)

A total of 11 growers were surveyed about their general N fertilization practices, representing 4,300 acres of Bartlett pears (Table 37). Three growers apply 60 lbs./acre/year or less, six growers apply 100 to 160 lbs., and two growers apply 175 to 200 lbs. The average rate used by all growers surveyed was 118 to 125 lbs./acre, and on an acreage basis the average was 124-131 lbs./acre. All but one grower uses split applications, and the grower applying all the N at one time uses the highest rate. Seven of the growers include a postharvest application (most in early fall), and several growers used about half to two-thirds of the total N in the fall. The most widely used fertilizer was calcium nitrate, which was used at least in part by seven growers. The method of application was split fairly evenly between broadcast and fertigation.

Table 37. Survey results, Sacramento Delta District, 2008 (Ingels, CPAB 2008 report). The survey covered 11 growers and 4300 acres. Quantity of fertilizer (nitrogenous, non-nitrogenous, compost or none) applied based, in part, on specific criteria, by percentage of orchards surveyed.

Grower	Fertilizer	$\#N_{act}/A/yr$	Criteria (in part) for quantity
1	CAN-17	60	
2	$CaNO_3$	60	Vigor
3	KNO_3	175	Vigor, Crop Load
	$CaNO_3$		
	CAN-17	175	
4	NH_4NO_3	150	Crop load
	$CaNO_3$		
5	$CaNO_3$ or CAN-17	120-140	
6	UN-32	40	Vigor
7	NH_4NO_3	120	Crop load, Vigor
	NH_4NO_3		
8	UN-32	150	
	UN-32		
9	$CaNO_3$	200	
10	$CaNO_3$	120	
	$CaNO_3$		
11	$CaNO_3$	100-160	Crop load
	Urea		

2010 Survey of Grower Practices in the North Coast District (Elkins, CPAB report); Tables 39 and 40.

The survey included almost 100% of growers, representing 53 orchard, 30 growers and 3850 acres. Forms of fertilizer containing N were summarized, as well as the $\#N_{act}/A/yr$ (1-46 $\#N_{act}/A/yr$) and the factors that go into decision-making by the growers. It is clear that the growers in the Late District have fertilizer practices, as far as N rate, that were significantly different than those of the Sacramento Delta District growers, however, growing conditions were quite different as well between the two districts. Vigor is more easily managed in the North Coast District, particularly by water management (water deficit), which is impractical in the Delta. All growers interviewed sample leaves for nutrient analyses – most on an annual basis, but two growers sampled every 2+ years and one grower sampled multiple times per year. Three growers also sample soils each year for analyses. Most growers stated that they based N fertilization rate decisions in part on leaf analysis, either their own evaluation or that of the lab report. Six of the growers said they also based the rate on crop load (lower rate if light, higher rate if heavy) and/or tree vigor (lower rate if vigorous, higher rate if weak). If fruit set is light, some growers will forego a late spring or early summer application to prevent excessive growth and/or to reduce expenses. Most growers generally see no obvious relationships in N rate vs. high vigor or N rate vs. fire blight, but about half have seen a relationship between high vigor and blight.

Table 39. Percentages of most of the North Coast District acreage z92010) represented by annual N use and the form of N fertilizer (3850 acres total). An additional 345 acres were fertilized with non-nitrogenous products and 235 acres fertilized with compost (N content unspecified).

$\#N_{act}/A/yr$	% of 3850 acres	Fertilizer products	% of total acres
1-10	21.5	15-15-15	8.1
11-20	7.8	19-19-19	8.7
21-30	28.2	20-20-20	4.2
31-40	12.3	Ammonium sulfate	2.5
41-50	7.9	$CaNO_3$	6.0
61-70	3.2	CAN-17	4.1
89	4.6	UN32	22.5
91-101	14.5	Urea	24.2
		compost, other organics	20.0

Table 40. Quantity of fertilizer (nitrogenous, non-nitrogenous, compost or none) applied based, in part, on specific criteria, by percentage of orchards surveyed in the North Coast District, 2010.

Calendar date as timing of fertilizer application	12.1
Chlorosis	1.1
Crop load	8.8
Economics of cost vs benefit	1.1
Experience/history of orchard needs and yield	16.5
New bud development desired	1.1
Soil sample	5.5
Tissue analysis	2.2
Tissue + soil analyses	5.5
Vigor/tree size	40.7
Extra from walnuts (a second crop)	1.1
Undetermined	4.4

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